USDA

ANNUAL RESEARCH REPORT
U.S. WATER CONSERVATION LABORATORY

1997

U.S. Water Conservation Laboratory
WATER SAVED IS WATER EARNED
Phoenix, Arizona

USDA - AGRICULTURAL RESEARCH SERVICE
Phoenix, Arizona

ANNUAL RESEARCH REPORT

1997

U.S. WATER CONSERVATION LABORATORY
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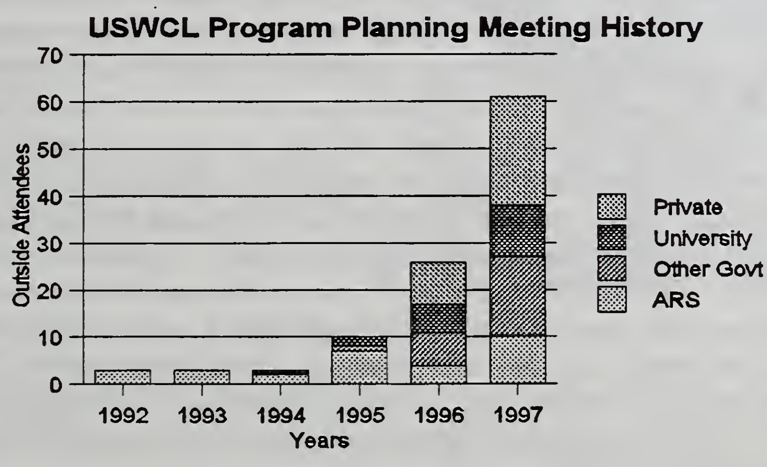
INTRODUCTION

The U. S. Water Conservation Laboratory (USWCL) Annual Research Report is intended to describe progress on our research projects in 1997 and plans for 1998 and beyond. Our targeted reading audience includes upper level management within the Agricultural Research Service, other ARS research locations and entities involved in natural resources research, and our many collaborators and cooperators. It is our intent to keep the individual reports short but informative; focusing on what is being done and why--the problem, objectives, approach, brief results, future plans, and cooperators involved in each program. We want to make sure that the product of the research and its contribution to water conservation are clear to all.



Efforts to identify and interact with users and to inform the public are part of an overall USWCL outreach program. The USWCL has a long tradition of reviewing its research program in an annual meeting each January. Over the past three years, efforts have intensified to identify our clients, inform them, and benefit from their insights. Until 1991, Annual Research Program Review and Planning Meetings included no outsiders. Since then, we have moved from 2 or 3 ARS outsiders in 1992-1994, to 10 ARS and university outsiders in 1995, to a broad cross section of 25 in 1996, and over 60 in 1997 (see graph). In these past two years, outside participants included private industry; universities; U. S. congressional offices; consultants; and federal, state, and county agencies. In 1997, participation was further broadened to include farmer representation. Also, in 1996 and 1997, some of the invitees were identified for their special interest in one of the five specific research programs ("targeted" users); while others were invited for their overall interest in USWCL research.

The USWCL has continued to be proactive in informing the public of current research activities. We had an informational booth at the Arizona Agricultural Day observance in downtown Phoenix that attracted a large number of primarily urban attendees. Resources to include agricultural activities in the classroom were provided to Arizona teachers by our participation in both the Agricultural Summer Institute and the Ag in the Classroom Resource Fair. The annual Science and Engineering Exposition continues to draw numbers of junior and senior high school classes to our laboratory to gain hands-on experience with agricultural research. This year the event was co-sponsored by the Maricopa County 4-H. We have also increased the number of educational resources on the worldwide web by including an on-line version of the study guide used in the science exposition and write-ups from our “Experiments for the Classroom” booklet.

These types of activities, along with the Annual Research Report, all provide opportunities for us to tell our research story and to assess and make our program more responsive to identified needs. Further, I invite you to visit the U. S. Water Conservation Laboratory homepage on the internet (**www.uswcl.ars.ag.gov**).

As a policy, we strive to leverage our available base funding into well-targeted, broader-based programs by attracting outside resources. We are committed to working collaboratively with other agencies and industry in bringing post doctorates, visiting scientists and engineers, graduate students, and persons on sabbaticals to the USWCL to maintain or expand our research programs. Outside resources are instrumental in our continued work in major program areas. In-kind human resources provided by many of our cooperators and collaborators

are highly significant in enhancing our programs, especially by each individual's stimulating effects on our research efforts (please refer to the list of Cooperators shown at the end of each report and summarized on pages xi through xiv). To the USWCL overall, this outside funding has represented from 10% to 15% of our total budget, but more important, it amounts to over half of our discretionary dollars.

I invite you to read and use this Annual Research Report. The research staff's telephone, fax, and e-mail numbers are on page vii). Let us know if there are questions or comments, either from a technical research standpoint or about ideas you might have regarding communication with our clients; all are invited and will be appreciated.

On a personal note--this will be the last Annual Research Report to be published under my directorship. I want to acknowledge the time and energy the U. S. Water Conservation Laboratory staff has devoted to keeping upper management and our many cooperators informed of our research; identifying and interacting with users, benefitting from their input; and reaching out to inform the public of agriculture and agricultural research. Our challenge is to continue to do good research, but that is not enough--we have to be sure we are dealing with real-world problems associated with agriculture. When increasingly less of the population is directly involved in farming, management of natural resources becomes more difficult since the consumer sees only the end product--food (from animals and plants) and fiber. The need for appropriate protection of the natural resource base from which these end products come and the associated cost are unknown to the typical consumer. But when we talk about sustainability of agriculture, we are really talking about how production agriculture impacts energy usage and some of our key natural resources--soil, water, and air--the three on which we in ARS, and especially at the U. S. Water Conservation Laboratory, are focusing. Again, our challenge is to focus on the right problems, getting input and guidance from all appropriate parties. It is not an additional job but integral to our job!

My thanks--keep up the good work!

Allen R. Dedrick, Director

DEDICATION

Robert J. Reginato was among the very first, in 1959, to join the growing cadre of researchers at the newly dedicated U.S. Water Conservation Laboratory. Working with "Kees" van Bavel, Lloyd Myers, Ray Jackson, Francis Nakayama, and Gary Frasier, Bob's initial inquiries into the physical properties of soils led to the development of the Tempe Cell for measuring soil moisture characteristics; theoretical analyses of energy and vapor transport in soils; and practical approaches for sealing soils in livestock ponds and water harvesting. Ambitious, round-the-clock experiments, which focused on comparisons of field-measurements with weighing lysimeters and having intriguing names like *Big Mud* and *Little Splash* were pure Reginato style. Turning his attention to remote methods for assessing soil properties, he began using gamma ray densitometry for inferring soil moisture content and obtained his Ph. D. on that topic from the University of California at Riverside in 1973.

Observing growing plants in the field added a complicating but necessary dimension to the experiments of traditional soil scientists. But the plants told Bob and his colleagues even more about the underlying soils. The Crop Water Stress Index (CWSI) was a revolutionary product for monitoring plant-available soil water that arose from Bob's quest to do quality research on issues that were important to agriculture. Coordination of large international experiments came naturally to Bob. Interdisciplinary field campaigns at The University of Arizona Maricopa Agricultural Center and the China Wheat Project brought international recognition to the Water Conservation Laboratory's remote sensing and agronomy programs. Scientists and technicians who worked with Bob the researcher remember the zeal and enthusiasm with which he tackled every project. He was the first, the last, and almost always the most energetic worker on the job regardless of the number of hours required or whether it involved digging an irrigation ditch or measuring plant temperatures.

Bob's leadership skills and administrative acumen are renowned. Less well known, perhaps, was how early he started sharpening those skills. Still wet behind the ears as a scientist, but displaying a nascent interest in management, Bob convinced Director Lloyd Myers that he needed a helper. The result was that he was appointed "Assistant to the Director," a position he retained until Lloyd moved up to the Area in 1972. Bob later served as Research Leader for the Soil, Plant, and Atmosphere Research Group at the Water Conservation Laboratory, and Associate Area Director and then Area Director for the Pacific West Area. His career culminated in February 1996, with his appointment as second in command in the Agency, the position of Associate Administrator of ARS in Washington, D.C.

Effective November of 1997, after more than 38 years with ARS, Bob decided it was time to retire. He had accomplished a number of important scientific and personal goals. He authored more than 150 scientific articles during his career. He was elected Fellow of the Soil Science Society America and also of the American Society of Agronomy.

Regarding the immediate future, Bob and his wife Donna plan to settle on the California coast, somewhere below San Francisco in a place with a view of the Pacific. With four married sons and five grandchildren, they'll now be able to spend more time with their family and take life a little slower.

There were few who suspected back in '59, when he first appeared on our doorstep, that Bob would have such a profound effect on the Laboratory, its staff, and the Agricultural Research Service. It has been a pleasure and honor to have worked with him over the years. Thus, it is with pride and gratitude that we dedicate the 1997 U.S. Water Conservation Laboratory Annual Report to him.

Ciao, Bob. Noi tutti desideriamo augurare a te ed alla tua famiglia in felice futuro. Ci mancherai molto ma il contributo che hai dato all'ARS rappresenta la tua preziosa eredità ed il nostro viatico per il futuro.

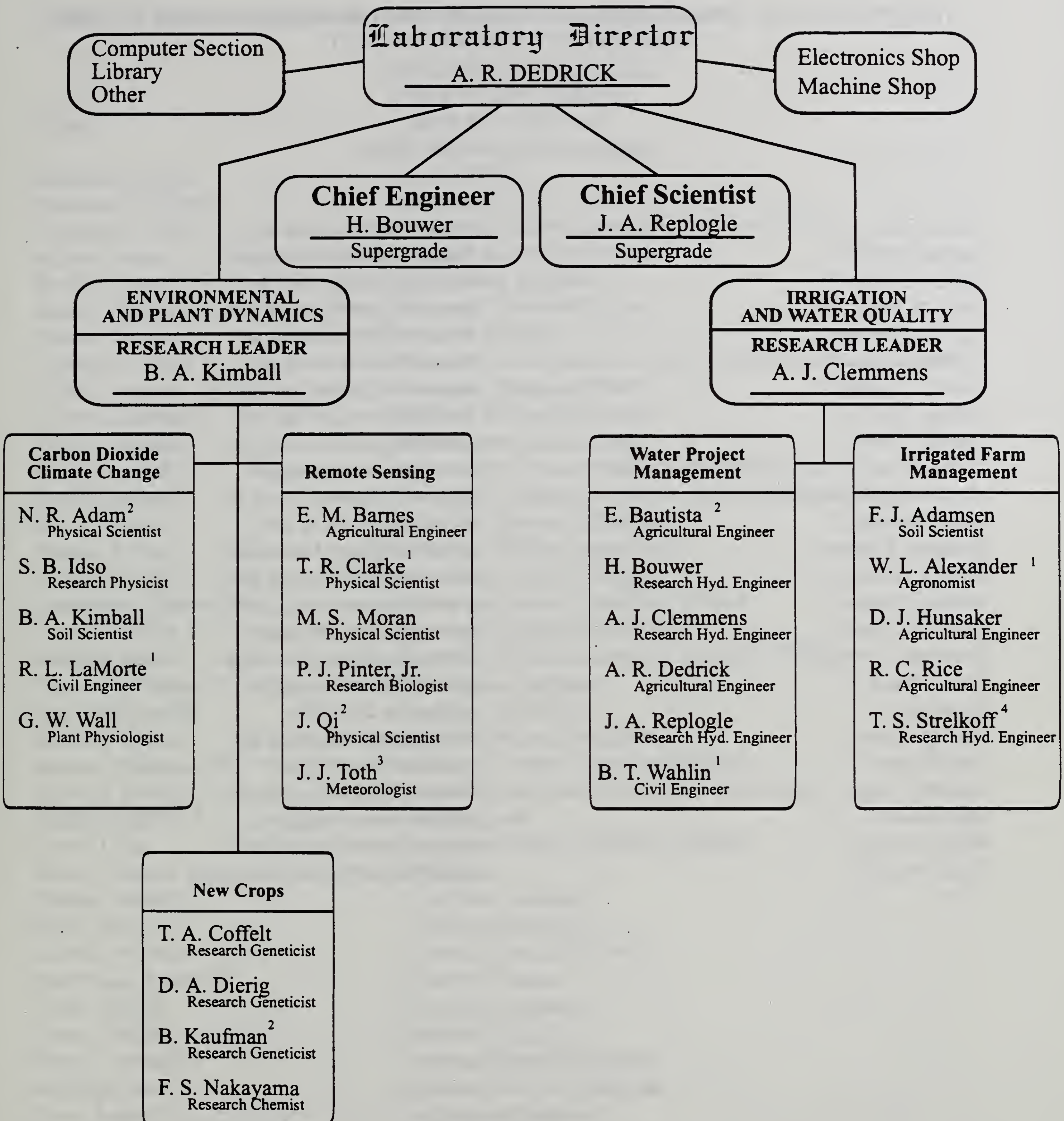
U. S. WATER CONSERVATION LABORATORY
ORGANIZATIONAL DESCRIPTION AND MISSION STATEMENTS

The mission of the U. S. Water Conservation Laboratory (USWCL) is to conserve water and protect water quality in systems involving soil, aquifers, plants, and the atmosphere. Research thrusts involve developing more efficient irrigation systems, improving the management of irrigation systems, developing better methods for scheduling irrigations, developing the use of remote sensing techniques and technology, protecting groundwater from agricultural chemicals, commercializing new industrial crops, and predicting the effect of future increases of atmospheric CO_2 on climate and yields and water requirements of agricultural crops.

The U. S. Water Conservation Laboratory research program is organized under two Research Units: Irrigation and Water Quality (I&WQ) and Environmental and Plant Dynamics (E&PD). I&WQ focuses on water management with emphasis on irrigation and water quality; E&PD concentrates on carbon dioxide-climate change, germplasm development for new crops, and remote sensing. Drs. Albert J. Clemmens and Bruce A. Kimball are the Research Leaders for the respective Research Units. The organizational structure for the USWCL is shown in figure 1, and the entire USWCL personnel list in table 1.

The mission of the Irrigation and Water Quality Research Unit is to resolve water management problems for irrigated agriculture through research aimed at conserving and augmenting water supplies. Goals are to develop management strategies and tools for the effective use of water and fertilizers in irrigated agriculture, develop tools for the protection of groundwater supplies from degradation as the result of agricultural practices, develop technologies for safe reuse of municipal wastewater, and transfer these results to practice through technology transfer efforts. The unit focuses on identifying individual actions and practices for resolving water supply and quality issues at the farm and project levels, and the various inherent interrelationships.

The mission of the Environmental and Plant Dynamics Research Unit is to develop optimum resource management strategies for meeting national agricultural product requirements within the context of global change. Goals are to predict increased CO_2 and global climate change effects on plant growth and water use; develop new crops to meet national needs for renewable, agriculturally-based products; and develop remote sensing techniques for farm management and wide-area evapotranspiration estimation. CO_2-climate research will furnish a knowledge base and models to assess global change impact on future agriculture, increasing the security of the world's food supply and benefitting all consumers. New Crops will contribute to the diversification of American agriculture while producing renewable sources of raw materials such as non-allergenic latex (medical products), hydroxy fatty acids (cosmetics and lubricants), and low pollutant epoxy fatty acids (paints and coatings). Remote Sensing research will benefit growers and consumers by improving farm management decisions and the accuracy of water resource assessments.



[1] Category 3 scientist
[2] Post-Doctoral Research Associate
[3] Post-Doctoral Research Associate (shared 50%/50% by U.S. Water Cons. Lab., Phoenix, and Southwest Watershed Research, Tucson)
[4] Research Professor, University of Arizona

Figure 1. U.S. Water Conservation Laboratory Organization, September 30, 1997

TELEPHONE, FAX, AND E-MAIL NUMBERS FOR THE U.S. WATER CONSERVATION LABORATORY RESEARCH STAFF

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Rice, Robert J.	rrice@uswcl.ars.ag.gov
Strelkoff, Fedja	fstrelkoff@uswcl.ars.ag.gov
Toth, James J.	toth@tucson.ars.ag.gov
Wahlin, Brian T.	bwahlin@uswcl.ars.ag.gov
Wall, Gerard W.	gwall@water1.uswcl.ars.ag.gov

Table 1. U. S. Water Conservation Laboratory Staff, September 30, 1997

PERMANENT EMPLOYEES

Name	Title
Adamsen, Floyd J.	Soil Scientist
Alexander, William L.	Agronomist
Arterberry, Carl A.	Agricultural Science Research Technician (Soils)
Askins, JoAnne	Physical Science Technician
Barnes, Edward M.	Agricultural Engineer
Bouwer, Herman	Research Hydraulic Engineer
Clarke, Thomas R.	Physical Scientist
Clemmens, Albert J.	Research Leader and Supervisory Research Hydraulic Engineer
Coffelt, Terry A.	Research Geneticist (Plants)
Colbert, Sharette N.	Physical Science Technician
Corris, Virginia D.	Office Automation Assistant
Dahlquist, Gail H.	Agricultural Science Research Technician (Plants)
Dedrick, Allen R.	Laboratory Director and Supervisory Agricultural Engineer
Dierig, David A.	Research Geneticist (Plants)
Draper, T. Lou	Secretary (Office Automation)
Gerard, Robert J.	Laboratory Support Worker
Gerszewski, Susette M.	Biological Science Technician (Plants)
Harner, Paulina A.	Secretary (Office Automation)
Heckart, Donna	Secretary (Office Automation) (retired 8-27-97)
Hunsaker, Douglas J.	Agricultural Engineer
Idso, Sherwood B.	Research Physicist
Johnson, Kathy J.	Physical Science Technician
Johnson, Stephanie M.	Biological Science Technician (Plants)
Kimball, Bruce A.	Research Leader and Supervisory Soil Scientist
LaMorte, Robert L.	Civil Engineer
Leake, Greg	Biological Science Technician (Plants)
Lewis, Clarence L.	Machinist
Mastin, Harold L.	Computer Assistant
Mills, Terry A.	Computer Specialist
Moran, M. Susan	Research Physical Scientist
Nakayama, Francis S.	Research Chemist
Pettit, Dean E.	Electronics Engineer
Pinter, Paul J., Jr.	Research Biologist
Powers, Donald E	Physical Science Technician
Replogle, John A.	Research Hydraulic Engineer
Rice, Robert J.	Agricultural Engineer
Rish, Shirley A.	Program Analyst
Rokey, Ric R.	Biological Science Technician (Plants)
Strand, Robert J.	Engineering Technician
Vinyard, Stephen H.	Physical Science Technician
Wahlin, Brian T.	Civil Engineer
Wall, Gerard W.	Plant Physiologist

LOCATION ADMINISTRATIVE OFFICE

Name	Title
Albright, Dixie	Safety and Occupational Health Specialist
Blackshear, Charlie	Custodial Worker
Farthing, Jesse	Maintenance Worker (resigned 10/24/97)
Gardner, Bruce	Office Automation Clerk
Hodge, Vanessa	Budget and Accounting Assistant
Hughey, David	Maintenance Worker
Johnson, Richard	Office Automation Assistant
Lee, Richard	Custodial Worker
McDonnell, Guy	Physical Science Aid
Martin, Kevin	Air Cond. Equipment Mechanic
Sexton, Judith	Purchasing Agent
Wiggett, Michael	Administrative Officer

TEMPORARY EMPLOYEES

Name	Title
Adam, Neal	Plant Physiologist
Adornato, III John	Biological Science Technician (Plants)
Bautista, Eduardo	Agricultural Engineer
Bross, Monique	Physical Science Technician
Bryant, Ross	Biological Science Technician (Soils)
Conley, Matthew	Biological Science Technician (Plants)
Draper, Karilee	Clerical Volunteer
Eggemeyer, Kathleen	Physical Science Aid
Eshelman, Trathford	Physical Science Technician (resigned 8/8/97)
Gallaher, Justin	Biological Science Aid
Gardner, Scott	Office Automation Clerk
Gladhart, Amanda	Office Automation Clerk
Helfert, Michael	Biological Science Technician (Plants) (resigned 9/28/97)
Holifield, Chandra D.	Biological Technician
Kaiser, Aaron R.	Biological Science Technician (Plants)
Kaufman, Benjamin	Research Geneticist (Plants)
Lee, Tali D.	Biological Science Technician (Plants) (resigned 3/29/97)
Luna, Traci	Biological Science Aid
McGarry, Sheldon	Physical Science Aid (resigned 8/30/97)
Mercy-Smith, Christy	Biological Science Technician (Plants) (resigned 8/11/97)
Miller, Ryan	Biological Science Aid (resigned 8/30/97)
Mitchell, Thomas A.	Engineering Technician (resigned 3/1/97)
Morgan, Stefani K.	Physical Science Aid (resigned 8/15/97)
Olivieri, José	Biological Science Technician (Plants)
Olivieri, Laura M.	Biological Science Technician (Plants)
Qi, Jiaguo	Physical Scientist

Richards, Stacy	Biological Science Technician
Salywon, Andrew M.	Biological Science Technician (Plants) (resigned 10/3/96)
Suich, Robert	Physical Science Technician
Tomasi, Belinda A.	Physical Science Technician (resigned 3/13/97)
Toth, James J.	Meteorologist

TEMPORARY STATE EMPLOYEES

Altamarano, Ramon	Research Aid
Baker, Michael G.	Research Specialist-Staff
Bhatt, Jayganesh M.	Research Aid
Brooks, Talbot J.	Research Technician
Dai, Feixiao	Research Assistant
Farr, Jon C.	Research Aid (resigned 10/31/97)
Jew, Wayne K.	Research Aid
Lewis, Laurie A.	Senior Machinist (Staff)
O'Brien, Carrie C.	Research Laboratory Assistant-Staff
Pabian, David J.	Associate Engineer (FACE)
Schmidt, Baran V.	Computer Programmer Assistant
Stierman, Heidi M.	Research Aid (resigned 4/28/97)
Strelkoff, Theodor S.	Research Hydraulic Engineer (Research Professor, U of A)
Tomasi, Pernell M.	Research Laboratory Assistant
West, Kathy S.	Biological Science Technician
Wolford, Karen K.	Laboratory Technician

U. S. WATER CONSERVATION LABORATORY
COOPERATORS DURING 1997

INSTITUTION	CITY/COUNTRY/STATE
Universities	
Arizona State University	Tempe, Arizona
California Polytechnic State University	San Luis Obispo, California
Colorado State University	Fort Collins, Colorado
Delft Technical University	Delft, The Netherlands
Free University of Amsterdam	The Netherlands
Harvard University	Cambridge, Massachusetts
Humbolt University	Berlin, Germany
Michigan State University	Lansing, Michigan
Northern Arizona University	Flagstaff, Arizona
Oregon State University	Corvallis/Medford, Oregon
Rutgers University	New Brunswick, New Jersey
Texas A&M University	Fort Stockton/College Station, Texas
Virginia State University	Petersburg, Virginia
University of Akron, Department of Polymer Science	Akron, Ohio
University of Alberta	Edmonton, Alberta, Canada
University of Arizona	Tucson, Arizona
College of Agriculture	
Cooperative Extension	
Dept of Plant Sciences	
Dept of Soil & Water Science	
Dept of Hydrology & Water Science	
Dept of Agric & Biosystems Engineering	
Office of Arid Land Studies	
Maricopa Agricultural Center	Maricopa, Arizona
University of California, Botany & Plant Sciences	Riverside, California
Universitat Autonoma	Barcelona, Spain
Universita della Tuscia	Viterbo, Italy
University of Essex	Colchester, United Kingdom
University of Florida	Gainesville, Florida
University of Georgia	Athens, Georgia
University of Guelph	Guelph, Ontario, Canada
University of Idaho	Moscow, Idaho
University of North Dakota	Fargo, North Dakota
University of Wisconsin	Madison, Wisconsin
University of Michigan	Ann Arbor, Michigan
Utah State University	
Dept. of Biological & Irrig. Engrg.	Logan, Utah

Federal Agencies

Farm Service Agency	Casa Grande, Arizona
National Irrig. Initiative	
National Assoc. of Cons. Districts	Lakewood, Colorado
U. S. Bureau of Reclamation	
Hydraulics Laboratory	Denver, Colorado
Lower Colorado Region	Boulder City, Nevada
Phoenix Area Office	Phoenix, Arizona
USDA, Natural Resources Conservation Service	Phoenix/Casa Grande, Arizona
	Dexter, Missouri
	Washington, DC
National Water and Climate Center	Portland, Oregon
USDA, Agricultural Research Service	
Carl Hayden Bee Research Laboratory	Tucson, Arizona
Conservation and Production Research Laboratory	Bushland, Texas
Foreign Disease-Weed Science Research	Frederick, Maryland
Grassland Protection Research	Temple, Texas
Great Plains Systems Research	Ft. Collins, Colorado
Hydrology Laboratory	Beltsville, Maryland
National Center for Agricultural Utilization Research	Peoria, Illinois
National Program Staff	Beltsville, Maryland
National Soil Dynamics Laboratory	Auburn, Alabama
National Agricultural Water Quality Laboratory	Durant, Oklahoma
North Central Plant Introduction Station	Ames, Iowa
Plant Stress and Protection	Gainesville, Florida
Soil & Plant Research	Fort Collins, Colorado
Soil/Water Conservation Research	Lincoln, Nebraska
Southwest Watershed Research Center	Tucson, Arizona
Subtropical Agricultural Research Laboratory	Weslaco, Texas
Tropical Crops & Germplasm Research	Mayaguez, Puerto Rico
U.S. Salinity Laboratory	Riverside, California
Water Management Research	Ft. Collins, Colorado
Water Management Research Lab	Fresno, California
Western Cotton Research Laboratory	Phoenix, Arizona
Western Integrated Cropping Systems Research	Shafter, California
Western Regional Research Center	Albany, California
Western Wheat Quality Laboratory	Pullman, Washington
USDA-CSREES, Office of Agricultural Materials	Washington, DC
U.S. Department of Energy	Washington, DC
Atmospheric & Climate Research Division	
Office of Health and Environmental Research	
USDI-U.S. Geological Survey	Santee, California
	Sacramento, California

State Agencies

Arizona Department of Agriculture	Phoenix, Arizona
Arizona Department of Environmental Quality	Phoenix/Tucson, Arizona

Arizona Department of Water Resources	Phoenix, Arizona
Phoenix Active Management Area	Phoenix, Arizona
Pinal Active Management Area	Casa Grande, Arizona
California Department of Water Resources	Sacramento, California
Irrigation Management Service	Casa Grande, Arizona
West Pinal Natural Resource Conservation District	Casa Grande, Arizona

Other

Agrigenetics	Madison, Wisconsin
Automata, Inc.	Grass Valley, California
Biosphere 2	Oracle, Arizona
Brookhaven National Laboratory	Upton, Long Island, New York
Buckeye-Roosevelt Natural Resources Conservation District	Buckeye, Arizona
CEMAGREF-Irrigation Division	Montpellier, France
Center for Irrigation Technology	Fresno, California
Central Arizona Irrigation & Drainage District	Eloy, Arizona
Central Arizona Water Conservation District	Phoenix, Arizona
Centre' d' Etudes Spatiales de la BIOspere	Toulouse, France
Coachella Valley Resource Conservation District	Indio, California
Electric Power Research Institute	Palo Alto, California
Gila River Farms	Pinal County, Arizona
CESBIO, CNES	France
GEOFLOW	San Francisco, California
GERSAR-SCP, Societedu Canal du Provence	Aix-en Provence, France
Global Water	Fair Oaks, California
Goddard Space Flight Center, NASA	Greenbelt, Maryland
Hunter Industries	San Marcos, California
Imperial Irrigation & Drainage District	Imperial, California
Institute of Geodesy and Cartography	Warsaw, Poland
Instituto de Agricultura Sostenible	Cordoba, Spain
International Flora Technologies	Gilbert, Arizona
Irrigation Association	Fairfax, Virginia
Irrometer Company	Riverside, California
Landcare Research	New Zealand
Maricopa Stanfield Irrigation & Drainage District	Stanfield, Arizona
Mexican Institute of Water Technology	Cuernavaca, Mexico
Mycogen, Plant Sciences	Madison, Wisconsin/San Diego, California
National Institute of Agro-Environmental Sciences	Tsukuba, Japan
Natural Heritage Division	Nashville, Tennessee
Nelson Irrigation	Walla Walla, Washington
Nu Way Flume & Equipment Company	Raymond, Colorado
Oak Ridge National Laboratory	Oak Ridge, Tennessee
Payne, Harold, Private Consultant	Higley, Arizona
Plasti-Fab	Tualatin, Oregon
Potsdam Institute for Climate Impact Research	Potsdam, Germany
Resource 21	Denver, Colorado
Salt River Project	Phoenix, Arizona

Superior Council for Scientific Research CSIC, AULA DEI	Zaragoza, Spain
TRACOR, GIE	Provo, Utah
Valmont Industries	Valley, Nebraska
Wellton-Mohawk Irrigation & Drainage District	Wellton, Arizona
Western Integrated Cropping Systems Research	Shafter, California

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IRRIGATED FARM MANAGEMENT

HIGH-FREQUENCY, SMALL VOLUME SURFACE IRRIGATION

D.J. Hunsaker, Agricultural Engineer; A.J. Clemmens, Supervisory Research Hydraulic Engineer; and W.L. Alexander, Agronomist

PROBLEM: The ability to apply light, frequent deliveries of water uniformly to crops with micro-irrigation is well recognized. However, very few attempts have been made to develop high-frequency, small volume irrigation management strategies for surface irrigation systems. This is because (1) most traditional surface irrigation methods are not capable of delivering small uniform quantities of water to the field, (2) changing surface irrigation system designs to accommodate smaller applications may require a large capital investment, (3) increasing irrigation frequencies will likely increase operating expenses, and (4) frequent irrigation scheduling will require a higher degree of management.

Prior research suggests that increased irrigation frequency has an effect on crop yields that could be economically significant. A recent two-year investigation in Arizona reported a 25% increase in yields when surface irrigations were applied once every five days during the cotton's peak boll development period, rather than once every 10-14 days. Studies on high-frequency level basin irrigation for cotton conducted by the USWCL in 1993 and 1994 demonstrated the feasibility and economic potential of high-frequency level basin design and management, as reported in the 1995 USWCL annual report. In the USWCL studies, yields were increased by about 10% when high-frequency was given only during the peak boll period. However, data obtained during these earlier USWCL studies also suggested that higher yields might be realized if high-frequency irrigations were continued beyond the peak boll development period. The objectives of this research are to determine the effects of small, frequent water applications on the water use, growth, and yield of cotton for both level basin and subsurface drip irrigation systems.

APPROACH: Field studies are being conducted at The University of Arizona, Maricopa Agricultural Center, on a 1.25-ha dead-level site equipped with a permanent subsurface drip irrigation system. In 1996 and 1997, cotton planted in April was grown at the site under low-frequency (LL) and high-frequency (HL) irrigation applications with level basin irrigation and under daily drip (DD) irrigation in 12 by 115-m plots. Each management was replicated three times in a randomized block design. Irrigation scheduling for the two level basin treatments was based on an allowable soil water depletion as determined with AZSCHED, a computer-based irrigation scheduling model developed by the Agricultural and Biosystems Engineering Department, The University of Arizona. The model incorporates local meteorological data with a crop coefficient curve for cotton and soil water holding characteristics of the site to calculate the daily water use and soil water depletion of the crop, and uses this data to predict the times and amounts for irrigation. The allowable soil water depletion used in the studies for the LL treatment was 55%. The allowable soil water depletion used for the HL treatment was also 55% until early boll development, and then it was changed to 30% to initiate the frequent, light irrigation regime for that treatment. The period in which frequent, small volume irrigation was applied to the HL treatment was begun in late June and continued through boll maturation (late August). Daily drip irrigation for the DD treatment was begun in early June 1996 and in late May 1997. Daily water application depths for the DD were adjusted during the season to match the estimated daily crop water use, as calculated by the AZSCHED program.

Data collected during the field studies included measurements of water applied for each irrigation, soil water contents, crop transpiration (1996 only), canopy reflectance and temperature, leaf area index, and plant biomass. In 1996 the cotton crop was defoliated on September 27, and yields were machine-harvested on October 18. The 1997 cotton will be harvested in October 1997.

FINDINGS: In 1996 (table 1), the daily drip irrigation treatment obtained the highest lint yield, 1278 kg ha^{-1}, with a total water application of 1010 mm. However, lint yield for the DD treatment was not significantly higher than that for the high-frequency level basin treatment (1203 kg ha^{-1}) that received a total water

application of 980 mm. Yields for the both the DD and HL treatments were significantly higher than that for the low-frequency level basin treatment (1055 kg ha^{-1}) that received a total water application of 965 mm. The yields for the DD and HL treatments represent a 21% and 14% increase over the LL treatment. The change in cotton yield due to high-frequency versus low-frequency level basin irrigation in 1996 was similar to that obtained in our earlier studies in 1993 and 1994. Results on cotton growth and development for the 1996 study are presented in "Remote sensing to monitor effects of plant stress on cotton growth and yield" by Holifield et al. (this volume). The 1997 cotton study has not been completed.

INTERPRETATION: The most prominent economic benefit from high-frequency level basin management is potentially higher yields. Previous work demonstrated that smaller, more frequent water applications can be uniformly applied to cotton in farm-scale level basins after normal soil cultivation operations cease at mid-season. High-frequency level basin irrigation is expected to increase cotton yields without increasing the total amount of water applied during the season, and without changing the irrigation method to more expensive pressurized systems. Using high-frequency level basin irrigation management should appeal to cotton growers operating under a small profit margin.

FUTURE PLANS: Plans are being developed to evaluate the efficacy of light, frequent water applications in level furrows with 32" cotton rows with irrigation in every other furrow and with conventional 40" rows with furrow compaction.

COOPERATORS: None.

Table 1. Average water applied and lint yields for drip and level basin treatments in 1996.

Irrigation treatment	Number of irrigations	Total water applied† (mm)	Lint yield (kg ha^{-1})
Daily drip (DD)	92	1010	1278 a*
High frequency level basin (HL)	13	980	1203 a
Low frequency level basin (LL)	9	965	1055 b

† Includes 125 mm of water from a preplant irrigation, plus rainfall totaling 37 mm throughout the growing season.

* Lint yield means followed by a different letter are significantly different at the 5% level using Duncan's Multiple Range test.

EVALUATION OF RAPE AND CRAMBE AS POTENTIAL WINTER CROPS TO REDUCE NITRATE ACCUMULATION IN THE SOIL

F. J. Adamsen, Soil Scientist; W. L. Alexander, Agronomist; and R. C. Rice, Agricultural Engineer

PROBLEM: Formation of nitrate during fallow periods in irrigated cotton rotation systems can lead to leaching of nitrate to groundwater when preplant irrigations are applied in order to make the soil suitable for tillage operations. One solution to this problem is growing a winter crop that utilizes residual nitrogen and nitrate mineralized during the winter. Due to the cost of water, any crop grown in the winter under irrigated conditions must have an economic return in order to gain producer acceptance, and a crop must be found that can be planted after cotton is harvested in the fall and can be harvested before cotton is planted in the spring. Two crops which may meet these restrictions are rape and crambe. Industrial rape and crambe both contain erucic acid which has industrial potential, and Canola types of rape are valuable as a source of unsaturated cooking oil. Both of these crops are short cool season crops that may meet the short growing season requirement and have a significant nitrogen requirement that would take advantage of residual nitrogen in the soil.

APPROACH: Research is being conducted through a series of field experiments to evaluate yield potential and maturity dates of rape and crambe. One variety of crambe, one variety of spring type industrial rape, and eight varieties of spring Canola type of rape were planted in the 1996-1997 growing season in 2 X 12.2 m plots on four planting dates from mid-October to early-December. Row spacing was 0.25 m. The spring industrial and two of the spring Canola types of rape are campestra types of the species *Brasica rapa* while the other Canola types of rape are from the species *B. napus*.

FINDINGS:. The earliest planting date had the highest yields for every variety of rape except Tobin (table 1). Frost on January 22, 1997, killed all of the Crambe but the rape did not appear to be affected by the cold temperatures. The study was planted on a site part of which had been used for a sweet corn herbicide trial during the spring of 1996. Carryover from the corn herbicides affected all of the planting dates to some extent. Yields of R-500 were reduced to near zero for the November and December planting dates. Yields of all varieties were reduced to some extent by the herbicides. In addition, CSU-045 and Tobin, both of which are *B. rapa* varieties, lodged badly late in the season. This resulted in additional reductions in yield of these two varieties. Lodging produced two effects on yield: first, the seed load on the plants when lodging occurred was damaged; and, second, the plants started to flower again, which delayed pod development resulting in a wide range of seed maturity in the plants.

INTERPRETATION: Problems encountered in the 1996-1997 growing season highlight several areas of investigation needed if rape and crambe are to be successful crops in the desert southwest. The lack of frost tolerance of crambe will limit the potential area in which it can be grown unless frost tolerant varieties can be found or developed.

Herbicide carryover devastated the rape crop during the 1996-1997 season. This is not the first time we have had this problem at this location. Full evaluation of the herbicide carryover will be necessary before growers plant large acerages of rape or crambe. While there is extensive literature available on herbicide carryover, additional information is needed on cotton defoliants and other potential chemical problems.

Lodging can be a serious problem in production. It reduces yields and makes harvesting more difficult. Correction of the lodging problems we noted in the *B. rapa* varieties may require changes in fertility practices, use of growth regulators, better genetic material, or some combination of the three.

FUTURE PLANS: In 1998, evaluation of rape and crambe will be continued with early maturing *B. rapa* varieties of rape from the Colorado breeding program, and earlier maturing and frost tolerant varieties of

Crambe will be sought. Experiments with growth regulators and fertility practices will be conducted in order to reduce lodging in susceptible varieties. Irrigation and other agronomic studies will be conducted to make the yields of winter crops economical. Additional studies will be initiated to determine the water and fertilizer requirements of rape and crambe under local conditions. The results of the planting date by variety trial and water use and fertility trials will be used to develop a rotation system with cotton that will provide year-round cover on the soil and should improve year-round nitrogen management.

COOPERATORS: Paul Raymer, Coastal Plain Experiment Station, Tiffton, GA; Larry Sernek, Agrigenetics, Madison, WI; Jennifer Mitchell-Fetch, University of North Dakota, Fargo, ND; Duane Johnson, Colorado State University, Fort Collins, CO.

Table 1. Rape yields in the 1996-1997 crop year at Maricopa Agricultural Center. All data are based on three replicates.

	Date of Planting			
Variety	30-Oct-96	30-Oct-96	20-Nov-96	11-Dec-96
ST-011	1798	665	841	534
TOBIN	807	841	426	178
HYOLA-029	873	901	692	603
CSU-045	1284	661	281	120
WESTAR	1258	513	402	487
A-112	1193	513	807	412
OSCAR	1714	1171	692	603
CYCLONE	1117	496	718	603
R-500	1140	781	72	0

USE OF A LOW-COST COLOR DIGITAL CAMERA TO MEASURE PLANT PARAMETERS

F. J. Adamsen, Soil Scientist; P. J. Pinter, Jr., Research Biologist; T. A. Coffelt, Research Geneticist; E. M. Barnes, Agricultural Engineer; R. C. Rice, Agricultural Engineer; and R. L. LaMorte, Civil Engineer

PROBLEM: Documenting crop senescence rates and other plant parameters such as fertility levels, insect damage, salinity problems, disease and nematode damage, etc., which result in changes in plant color, is often difficult due to the need for frequent sampling during periods of rapid change and the subjective nature of visual observations. Digitized images of crops should show temporal changes in the greenness of crop plants as well as differences related to treatments. A second area of interest is the number and timing of flowers a plant produces because it can be an important factor in determining yield. The time required to count flowers manually in the field makes it difficult to carry out large studies involving flower numbers. Again, it should be possible to detect flowers on plants which are not obscured by leaves and stems. Low cost digital cameras which are becoming available in the market provide an easy and inexpensive method of obtaining digital images of plants that can be analyzed for a number of parameters.

APPROACH: A digital camera costing less than $1000 is being used to obtain images of plants in a number of field experiments. Several types of greenness measurements were made as part of an experiment to determine the effects of elevated CO_2 and limited soil nitrogen on spring wheat at The University of Arizona, Maricopa Agricultural Center (MAC), near Phoenix, Arizona. A Free-Air CO_2 Enrichment (FACE) apparatus was used to expose the crop to 200 μmol mol^{-1} above ambient CO_2 levels. Each CO_2 treatment was divided into high and low levels of nitrogen application. High-N treatments received 350 kg ha^{-1} of N and low-N treatments received 15 kg ha^{-1} of N. "Greenness" measurements were made during senescence of the crop using a color digital camera, a hand-held radiometer, and a SPAD chlorophyll meter. The ratio of the average green to red (G/R) digital numbers were computed for a cropped image from a digital camera representing 1 m^2 for each treatment and sample date. The normalized difference vegetation index (NDVI) was calculated from the red and near-infrared canopy reflectance measured with a hand held radiometer. A SPAD reading was obtained from randomly selected flag leaves.

A study was undertaken using a true color digital camera to determine the feasibility of using images from the camera to count flowers of several varieties of rape *(Brassica napus* and *B. Rapas*) and of lesquerella (*Lesquerella fendleri*) automatically. The camera had a 1024 by 768 pixel resolution and twenty-four bit color resolution. Images of the rape were taken once per week and of the lesquerella two times each week during the flowering period. The first step in processing the images was to crop the image so that it showed an area of 1m by 1m. Since both of the species of interest have yellow flowers, all pixels with yellow color were identified. A shape filter was applied to the image to reject pods and stems that had turned brown and resulted in false positives. Spots of yellow color were then counted and an overall index of yellow was calculated.

FINDINGS: All three methods of measuring plant greenness showed similar temporal trends. The relationships between G/R with NDVI and SPAD were linear over most of the range of G/R (Fig. 1). However, NDVI was more sensitive at low values than G/R (Fig. 2a). G/R was more sensitive above G/R values of 1.2 because the upper limits of SPAD measurements were constrained by the amount of chlorophyll in the leaf, while G/R responded to both chlorophyll concentration in the leaves as well as the number of leaves present (Fig. 2b).

Software developed for a Pentium 133 computer was used to crop the image to represent 1 m^2 and reduce the image to only black and yellow. Yellow areas associated with stems and pods were eliminated by using a two dimensional low pass filter. The area of flowers was then calculated and the number of yellow spots counted to produce a flower count (Fig. 3). Flowers peaked in April. One of the key steps in the method was establishing the threshold values for red and green that represent yellow flowers. The results of these automated procedures were well correlated with manual counts (Fig. 3).

INTERPRETATION: Two diverse problems were addressed using a digital camera. In the first case, the camera was used to document the changes in plant color associated with senescence of wheat. The results compared favorably with NDVI and SPAD chlorophyll measurements (Fig. 1). However, there were differences in performance among the three methods of measuring plant greenness. Some of these phenomena may be explained by considering the unique wavebands that are utilized in each of the greenness indices and the optical properties of the various plant tissues involved. Differences in sensor field-of-view may also have been partly responsible. The 1 m by 1 m digital camera image used in the analysis subtends an angular field-of-view of approximately 36° and thus includes proportionately more heads and awns than either NDVI (15° field-of-view) or SPAD (single point) indices.

Flower indices can be developed for the crops studied. The results indicate that flowering indices can be developed for any plant with appropriate architecture. That is flowers are produced at the ends of stems, as with lesquerella or on a flowering stalk that projects above the leaves as with rape. In combination with biological data on the duration of individual flowers, it may be possible to use flowering indices to compute optimum harvest dates for indeterminant crops that maximize economic value based on both yield and quality.

FUTURE PLANS: Greenness indices will be developed for other crops, including sorghum and alfalfa. The use of greenness indices with forage crops can help assess the effects of various treatments on regrowth and harvest date. Methods for evaluating vernonia flowering will be developed. Additional development is needed since vernonia flowers are blue, unlike rape and lesquerella which are yellow. This crop should test the applicability of the general methodologies developed for rape and lesquerella. If this effort is successful, the feasibility of counting flowers on other crops, such as cotton, will be evaluated.

COOPERATORS: John Nelson, The University of Arizona, Maricopa Agricultural Center

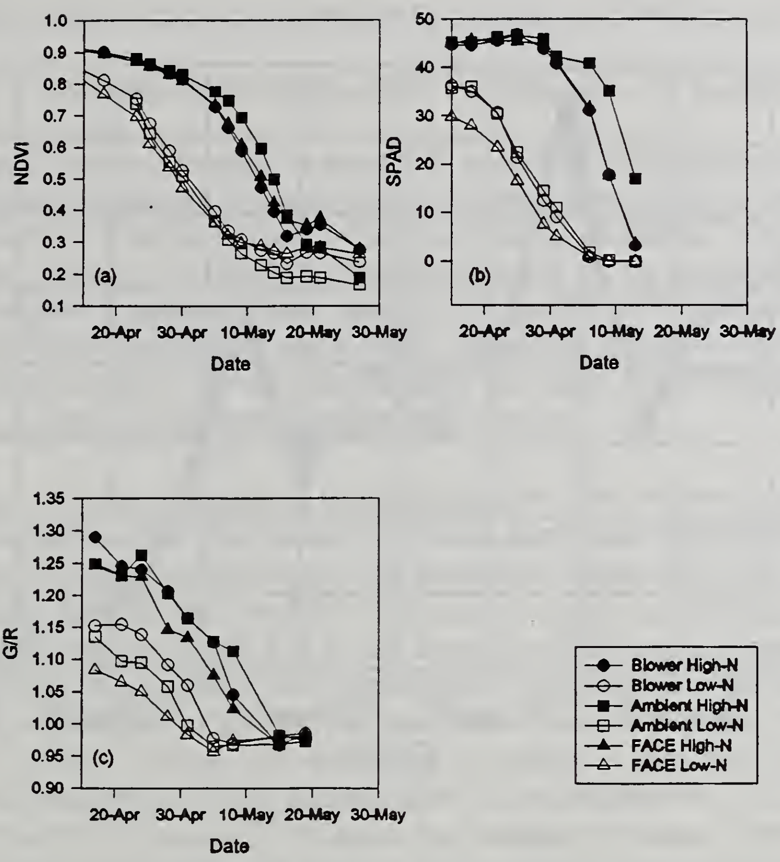

Figure 1. Temporal changes in normalized vegetation index (NDVI), Minolta SPAD meter, and ratio of green to red (G/R) of wheat.

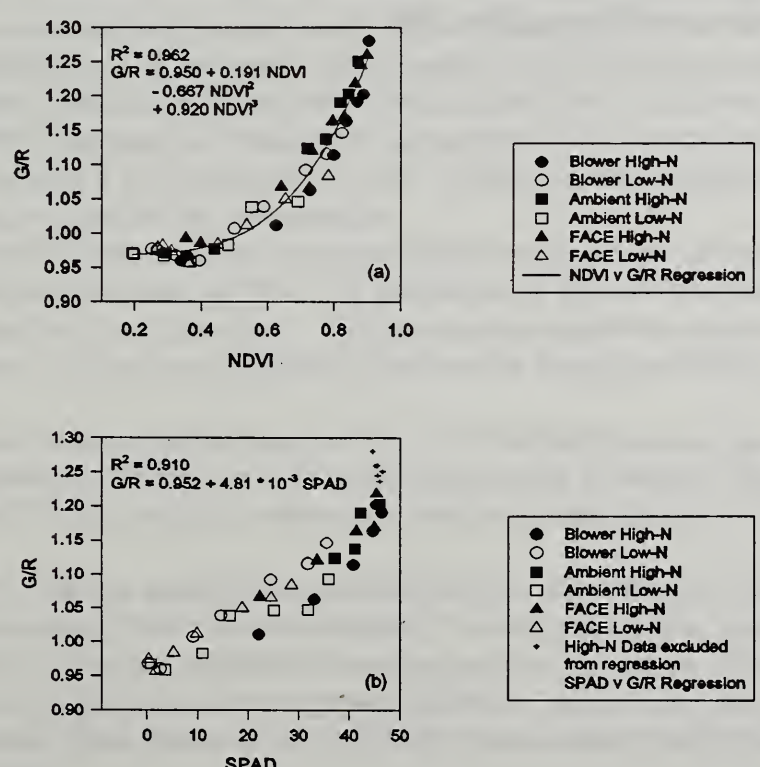

Figure 2. The relationship of normalized vegetation index (NDVI) and SPAD-502 value to green to red ratio (G/R) for wheat.

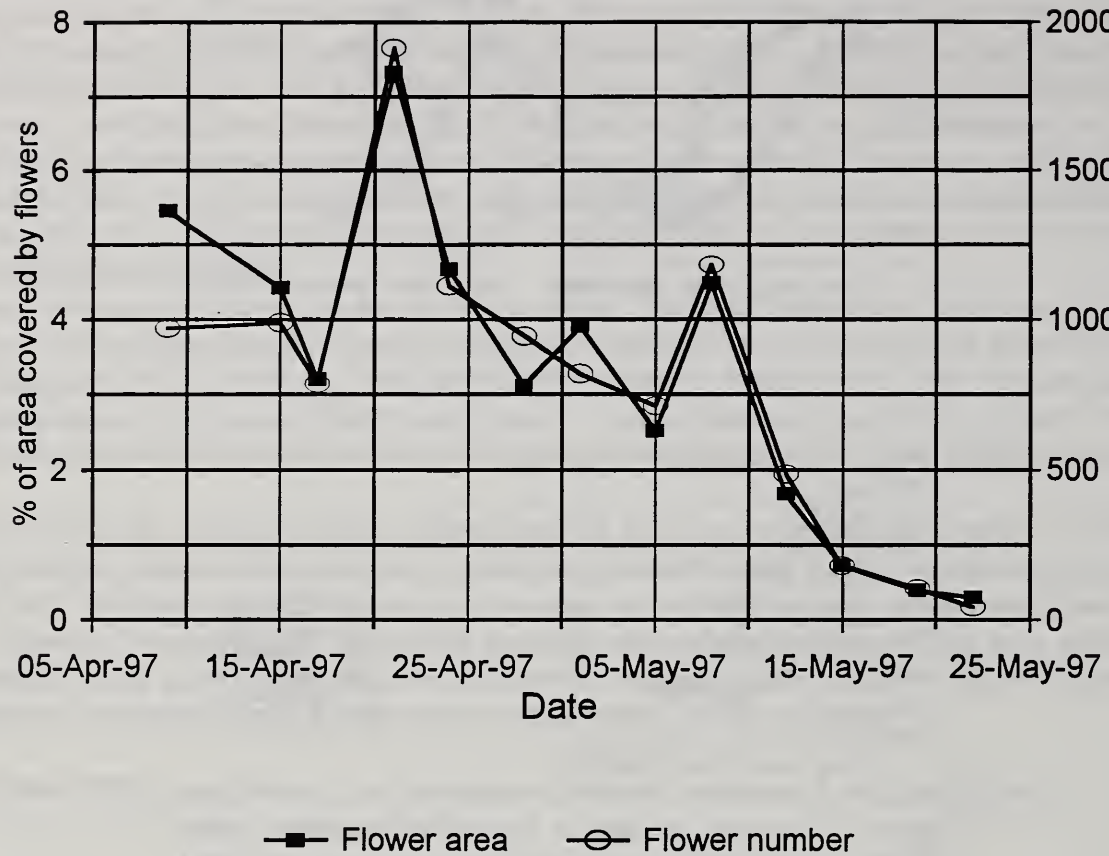

Figure 3. Area of image occupied by flowers and flower number on 0 nitrogen, 3.8 kg ha^{-1} seeding rate, lesquerella treatment from April through May 1997.

ASSESSMENT OF NITRATE LEACHING UNDER COMMERCIAL FIELDS

R.C. Rice, Agricultural Engineer; and F.J. Adamsen, Soil Scientist

PROBLEM: Application of excess nitrogen to crops such as cotton and subsequent application of excess irrigation water can result in movement of nitrate to groundwater. When nitrate is found in groundwater, agriculture is usually assumed to be the source of the contamination. A number of surveys of Midwestern fields indicate that farm practices are responsible for at least part of the nitrate that finds its way into groundwater. Under irrigated conditions, nitrate leaching is a function of irrigation efficiency and spatial variability as well as fertilizer management, which makes assessment of the problem more complex. The objective of this study was to monitor the movement of water and nitrate in the soil profile on a commercial production field before and after management practices were changed.

APPROACH: Research is being conducted by taking soil samples from commercial fields before planting and after a crop has been harvested. Three transects are taken across each field with five samples taken in each transect. Spacing of samples along the transect was based on the length of the run. The first sample was taken 10% of the run length from the top of the field. The next four samples were taken 20% of the run length apart. A 2-m by 2-m area is amended with KBr before the start of the growing season so that the depth of penetration of that season's irrigation water can be determined. The positions in the transect are numbered from one to five starting at the upper end of the field. Samples are taken to a depth of 270 cm and analyzed for ammonium, nitrate, bromide, chloride, and texture. In an attempt to improve irrigation efficiency, the producer changed cultural practices in 1996 by decreasing the row spacing from 40 to 32 inches and irrigating every other row. The effective row spacing for irrigation then changed to 64 inches. Water samples are taken from each irrigation and the concentrations of chloride, nitrate, and ammonium determined. Flumes were installed to allow measurement of water entering and leaving the field. Automated data collection systems were operated during each irrigation during the growing season for cotton.

FINDINGS: The total water applied, percent runoff, and effective irrigation amount for each irrigation are shown in table 1 for the four years of the study. After changing to the 32-inch rows and irrigating every other row, the runoff decreased from 21% in 1994-1995 to 14% in 1996-1997. One to two fewer irrigations were applied in 1996 and 1997. Changing the irrigated row spacing from 40 to 64 inches decreased the infiltration area by 38% which resulted in a 33% reduction in runoff. While the percent runoff was greatly reduced, the average depth infiltrated was similar for both practices.

Bromide was observed at all depths before and after cultural practices were changed as shown in figure 1. The bromide concentration was lower in 1994. The distribution of bromide was similar in 1995 and 1996 showing a distinct peak at the 1.5 to 1.8 m depths. This peak corresponds with a nitrate peak at about the same depth as shown in figure 2. There was no difference between the bromide and nitrate distribution for either management practice.

Distribution of bromide down the rows is shown in figure 3. The distribution was similar for both practices. Greater depth of penetration of bromide occurred in the upper portion of the field. The peak concentration at the upper end of the field (45 m), was at 2m, whereas the peak occurred at about 1m at the lower end (405 m).

INTERPRETATION: The new cultural practice resulted in less runoff from the field. Nitrate distribution in the soil profile was not altered. Detection of bromide at 2.7 m indicated leaching potential of nitrate and was similar for both practices. Irrigation uniformity down the rows was not altered. More leaching occurred at the upper end of the field which was due to a greater infiltration opportunity time. Additional changes in management practices on this field, such as shorter length of run and altering nitrogen application patterns, may help in less nitrate leaching.

FUTURE PLANS: Additional data relating to fertilizer applied and yields will be obtained for the producer to determine how effective the practice changes were.

Table 1. Total water applied, percent runoff and depth infiltrated for different years.

	1994				1995		
Date	Average infiltration	Runoff	Water applied	Date	Average infiltration	Runoff	Water applied
	inches	%	inches		inches	%	inches
May 17	6	18	7	May 20	6	22	7
June 6	3	22	4	June 8	3	23	4
June 17	4	22	5	July 1	6	21	7
June 27	6	23	8	July 11	4	22	5
July 6	3	31	4	July 21	3	29	5
July 13	2	27	3	July 29	5	20	6
July 22	4	21	5	Aug 5	5	23	7
July 31	4	17	5	Aug 16	2	31	4
Aug 6	4	21	5	Aug 24	3	21	3
Aug 15	6	14	7	Sep 2	4	14	5
Aug 27	5	17	6	Sep 11	3	17	4
Sept 7	3	19	4				
Total	49		62	Total	44		57
Average		21		Average		22	

	1996				1997		
Date	Average infiltration	Runoff	Water applied	Date	Average infiltration	Runoff	Water applied
	inches	%	inches		inches	%	inches
May 24	4	15	5	May 16	8	4	8
June 13	3	15	4	June 2	7	11	8
June 21	4	14	5	June 13	3	15	4
July 2	6	12	6	June 24	4	19	5
July 12	6	15	7	July 3	3	22	4
July 21	4	15	5	July 12	6	23	7
July 31	4	15	5	July 26	4	20	5
Aug 9	6	12	6	Aug 5	6	15	6
Aug 19	6	6	6	Aug 15	4	14	5
Aug 29	6	7	6	Aug 25	5	9	6
Total	48		55	Total	50		59
Average		13		Average		15	

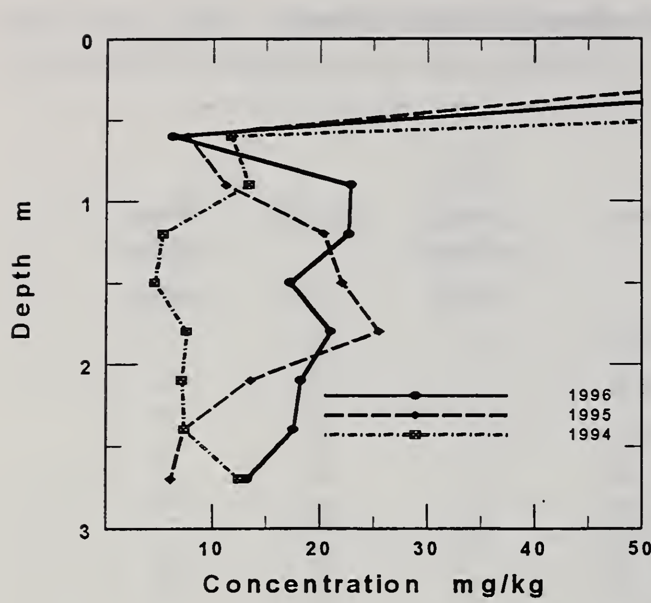

Figure 1. Bromide concentration with depth

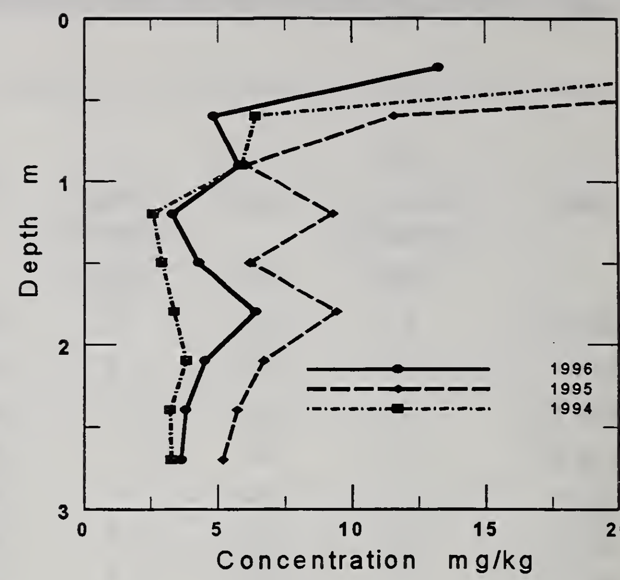

Figure 2 . Nitrate concentration with depth.

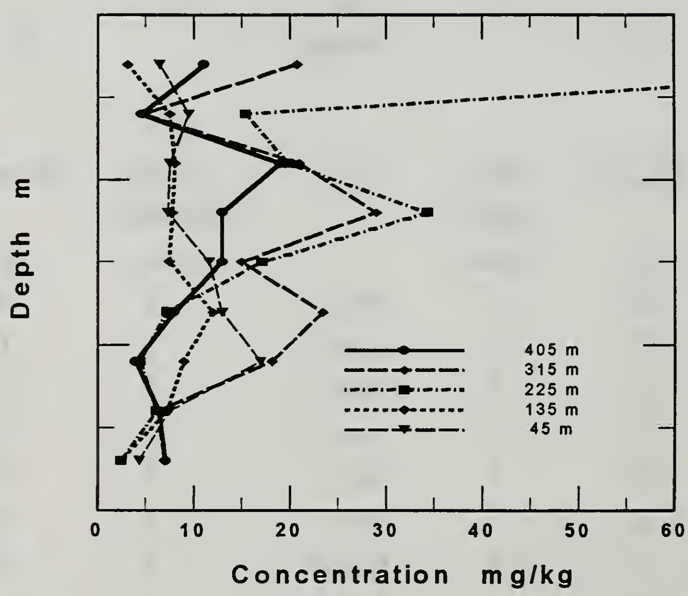

Figure 3. Bromide concentration with depth and position down the row.

IRRIGATION INDUSTRY-ARS COLLABORATIVE EFFORT[1]

A. R. Dedrick, Supervisory Agricultural Engineer; and
D. F. Heermann, Supervisory Agricultural Engineer

PROBLEM: The "Irrigation Industry-ARS Collaborative Effort" was initiated in 1991, led by Dedrick and Heermann, to promote a concerted, sustained effort to impact irrigation on a broad scale up through the national level. It aimed to address issues facing irrigation as a whole. At its January 1992 meeting, the Collaborative Effort formulated the following general role statement, which has guided its operations since:

The Collaborative Effort provides a framework for the Irrigation Industry and the Agricultural Research Service to foster and focus an ongoing partnership in support of irrigation that yields optimal societal benefit.

APPROACH: In May 1991, a workshop with over 40 attendees, almost evenly divided between the Irrigation Industry and ARS irrigation and drainage researchers, met to launch the effort. At that meeting, a Leadership Group (see table 1 for current Leadership Group members) was mandated to lead the Collaborative Effort. Over the last six years, the Leadership Group has guided actions to address the agenda that emerged from the workshop, including meetings to adjust overall Collaborative Effort plans and to review and support its workgroup activities focused on three main thrusts:

- **Focusing Resources on Irrigation's Highest Research Priorities**
- **Increasing and Facilitating Collaborative Research**
- **"Telling the Story" (developing a common advocacy voice for irrigation, contributing to appropriate balance of competing water demands, and impacting public perceptions related to irrigation)**

FINDINGS: Key activities and results of the Collaborative Effort over the past year include the following (see "Annual Research Reports," 1993-1996, for earlier activities):
(1) <u>Collaborative Effort (CE) Leadership Group Meetings</u>. (a) The CE Leadership Group held a two-day meeting in San Antonio on October 31-November 1, 1996, in conjunction with the Irrigation Association (IA) Expo. The main thrust of the meeting was to come to an understanding of how irrigation and its future are viewed in two important studies, *A New Era for Irrigation* and *The Future of Irrigation*, both published in October 1996 by, respectively, the National Research Council Water Science and Technology Board (WSTB) and the Council for Agricultural Science and Technology (CAST). Because of the implications of the two studies to the broader current context of competition for water and other challenges, representation for this meeting was broadened to include other entities potentially interested in working together in support of irrigation. In addition to Irrigation Industry and ARS Leadership Group members, participants included representatives of NRCS, USBR, the National Irrigation Initiative-National Association of Conservation Districts (NII/NACD), and the IA Executive Committee. (b) A half-day Leadership Group meeting was held in Nashville on November 2, 1997, again in conjunction with the IA Expo. Representatives of NRCS, the IA Executive Committee, and NII/NACD again participated. Discussions focused on an update of significant changes in ARS program structure and delivery resulting from the development of ARS "National Programs," now underway, and the future of Collaborative Effort-type activities. The latter resulted in a proposal that

[1] Dedrick and Heermann (Water Management Research, Ft. Collins, Colorado) have co-chaired the Collaborative Effort. Key input to the process has been provided by J. A. Chapman, Valmont Industries, Valley, Nebraska; L. E. Stetson, ARS, Lincoln, Nebraska; and S. A. Rish, ARS, Phoenix, Arizona, as Sub-group Co-Chairs for primary thrusts; T. A. Howell, ARS, Bushland, Texas, for development of the "yellow pages"; and consultant D. B. Levine (Management/Team-Building Specialist) for overall facilitation of the Collaborative Effort.

an IA-agency group be established to succeed the present Leadership Group. The IA will organize the first meeting of the new group, which would include agencies and other entities who participated in the 1996 and 1997 Leadership Group meetings, a few targeted users, and other agencies and entities.

(2) Outreach Activities: (a) The directory of "Irrigation & Drainage Research in the Agricultural Research Service" (the "yellow pages")[2] was put up on the internet on the ARS home page (http://www.ars-grin.gov/ars/id). (b) Articles on ARS irrigation and drainage research continued to be submitted to the IA bi-monthly publication *Irrigation Business and Technology*. The articles consist of a national-level introduction by the National Program Leader for Water Quality and Water Management and brief summaries of current research from irrigation and drainage locations. (c) For the seventh consecutive year, outreach efforts, including "how-to" information for entering into Cooperative Research and Development Agreements (CRADAs) with ARS, were extended through the Collaborative Effort exhibit at the 1997 IA Expo, held in Nashville in November 1997. The exhibit included an on-line demonstration of the internet I&D directory. Support for the exhibit continued to be provided by IA and the ARS Offices of Technology Transfer and Information. The exhibit was staffed by ARS locations in Phoenix, Arizona; Ft. Collins, Colorado; Lubbock, Texas; Florence, South Carolina; Kimberly, Idaho; Lincoln, Nebraska; Baton Rouge, Louisiana; and Athens, Georgia.

INTERPRETATION: Since the inception of the Collaborative Effort in 1991, the combined efforts of the Irrigation Industry and ARS have produced significant accomplishments, that can be expected to have continuing impact (see table 2). Further, the approach used with the Irrigation Industry has potential as a model for building partnerships between ARS and other client groups, especially as we in ARS move toward more client involvement in our research program development and assessment (i.e., ARS's response to the Government Performance and Results Act.).

Of the original Collaborative Effort thrusts, the identification of and response to priority research needs require the most coordinated ongoing action. Given the IA's advocacy role for irrigation and related concerns, the proposed new IA-agency group would seem an appropriate instrument to pursue that end. Such a group could also function as a resource for ARS locations and programs at whatever level input is needed. All participating entities would benefit from timely sharing of information.

FUTURE PLANS: The IA plans to convene an initial meeting of the proposed new group, consulting with agency representatives to determine appropriate participants. Thought will be given to the various Collaborative Effort outreach activities to determine how to carry them forward most appropriately.

COOPERATORS: Cooperators are included in table 1.

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[2] The "yellow pages" lists current ARS I&D researchers by location with their areas of expertise, and the accomplishments and publications of each of the fourteen I&D locations.

Table 1. Irrigation Industry-ARS Collaborative Effort Leadership Group members and affiliations

Industry and End User Members	ARS Members
John A. Chapman, Valmont Industries, Valley, NE	Dale A. Bucks, National Program Staff, Beltsville, MD
Richard E. Hunter, Hunter Industries, San Marcos, CA	Allen R. Dedrick, U. S. Water Conservation Lab., Phoenix, AZ
Thomas H. Kimmell, The Irrigation Association, Fairfax, VA	Dale F. Heermann, Water Management Research, Ft. Collins, CO
Thomas E. Levy, Coachella Valley Water Dist., Coachella, CA	Terry A. Howell, Conservation and Production Research Lab., Bushland, TX
Barton R. Nelson, Nelson Irrigation, Walla Walla, WA	Shirley A. Rish, U. S. Water Conservation Lab., Phoenix, AZ
Claude J. Phene, Irrigation Consultant, Fresno, CA	LaVerne E. Stetson, Soil/Water Conservation Research., Lincoln, NE
William R. Pogue, Irrometer Co., Riverside, CA	
Rodney Ruskin, GEOFLOW, San Francisco, CA	
Kenneth H. Solomon, Calif. Polytechnic State Univ., San Luis Obispo, CA	

Table 2. Following is a summary of Irrigation Industry-ARS Collaborative Effort accomplishments, 1991-1997, related to the originally identified thrust areas:

- *Thrust*: **Focusing Resources on Irrigation's Highest Research Priorities**
  - Established/reactivated Research Committee in IA.
  - Research opportunities:
    - Developed research priority list (11/92).
    - IA representatives presented list to ARS (5/93, letter to ARS; 9/93, meeting with ARS).
    - Research Committee met first time (11/93)
    - ARS developed a response to IA Research Opportunity List (1/94, letter from National Program Leader to ARS I&D locations; 11/94, National Program Leader presented results of ARS research location survey to IA Research Committee).
    - Additional prioritization done by Research Committee 1994, 1995, 1996.

- *Thrust*: **Increasing and Facilitating Collaborative Research**
  - Published a Directory of Irrigation & Drainage Research in ARS (three editions 1992 - 1996).
  - Put the I&D directory up on ARS internet home page.
  - Developed a "how-to" tri-fold of first steps in developing CRADAs.
  - Publicized the Collaborative Effort through numerous news releases.
  - Initiated an ARS feature article to appear in each issue of *Irrigation Business & Technology*, highlighting ARS irrigation-related research.

- *Thrust:* **"Telling the Story" (developing a common advocacy voice for irrigation; contributing to appropriate balance of competing water demands; and impacting public perceptions related to irrigation).**
  - Proposed and supported a study by the Water Science and Technology Board of the National Academy of Sciences-National Research Council focusing on the future of irrigation in the U. S. The study report, *A New Era for Irrigation*, was published by the National Academy Press in 1996.
  - Functioned as an informational resource to IA's Legislative Action Committee.
  - Fostered alliances/coalitions (NRCS, USBR, National Association of Conservation Districts, National Irrigation Initiative).

APPLICATION OF DRAIN-BACK LEVEL-BASIN SYSTEMS

A. R. Dedrick, Supervisory Agricultural Engineer

PROBLEM: In the mid-1980s, in collaboration with a farmer, a novel level-basin irrigation system was developed in which a portion of the applied water is drained off the basin. I called the system "drain-back level basins," and with Bert Clemmens, developed design, construction, management, and operational procedures for their use. The drain-back level-basin (DBLB) system, unlike most surface irrigation systems, allows the application of small amounts of water per irrigation (less than two inches under some conditions), a highly desirable feature. The drain-back system features an earthen water conveyance channel that can be used to both irrigate (i.e., applying irrigation water) and surface-drain level basins (i.e., draining back some of the applied irrigation water or removing excess surface water from either over-irrigation or rainfall). The drainage aspects of the system extend the area of application of level basins to high rainfall zones and build on evaluations of level basins in high rainfall zones (graduate work done by Yvonne Reinink in the early 1980s). Since the system features earthen channels rather than concrete-lined ditches or closed-pipe water distribution systems commonly used with conventional level basins, the DBLB system is easier and less costly to construct than conventional level basins.

The farmer with whom we originally worked, Vess Quinlan in southern Colorado, developed significant acreage using the drain-back system. In 1983, we did an extensive on-farm evaluation of his system, finding that it worked very well. That experience led us to undertake further evaluation and documentation of the DBLB system, conducting field experiments to quantify the performance of the DBLB system and developing a data base for hydraulic model verification from carefully conducted field studies on precision-leveled furrows. These experiments resulted in a number of publications, both technical and popular, on the use of DBLBs. The objective of this report is to provide an update on the adoption of DBLBs in Arizona over the last year.

APPROACH: **Recent Implementation**--DBLBs have been and continue to be installed on a several-hundred-acre farm in central Utah and currently are seeing rapid adoption in central Arizona where several systems have been installed on farms since early this year (1997). The rapid adoption in Arizona has been initiated by Mr. Harold Payne, a private consultant to farmers in central Arizona, who is moving the idea/technology into practice. Mr. Payne attended the USWCL research program planning meeting in January 1997 and brought up the potential use of drain-back systems. He provided the following note to me after the meeting:

> *"Our work group at the meeting called the lack of adoption/publicity of drain-back systems the good news-bad news-good news story. The first part of the good news is that there is an inexpensive alternative to traditional level basin systems and it has superior water management capabilities. The bad news is that it [the technology] has been sitting in the files of the U. S. Water Conservation Laboratory for at least 13 years. The second part of the good news is that it is not too late for most people to take advantage of this innovation. Less than a third of the irrigated lands in Pinal Country and even a smaller percentage of lands in Maricopa County have been converted to the more expensive level basin systems using high-capacity concrete ditches."*

Payne's remarks are well taken, pointing out the need for introduction and adoption of the DBLB technology. Because of Payne's innovation, the technology is now moving forward rapidly. Most of the data reported herein were provided by Mr. Payne, both from his correspondence with me after the review meeting last January and from some of his work with clients since about December 1996. During the start-up of some of the DBLBs, USWCL staff provided guidance for sizing the earthen channel and drop structures. Also, I gave two presentations on DBLBs to farmers, contractors, consultants, and extension and NRCS personnel.

Description of DBLBs--The drain-back level-basin system consists of a series of terraced level basins. An earthen channel is used to convey, spread, and divert the water directly onto the basin surfaces. Each basin is irrigated separately by checking the water in the earthen channel reach bordering the basin to be irrigated. The water level is raised by closing a gate at the drop to the next bench. The irrigation proceeds in a

downstream direction (i.e., from the top bench to the bottom bench). The drainable portion depends on the length of the basin, the amount of water on the basin surface (or in furrows) at the time the irrigation is changed, and the infiltration characteristics of the soil. A broad, flat, conveyance-distribution-drainage channel is used. A typical channel can be approximated by a trapezoidal shaped canal with 4:1 side slope on the side leading to the basins and about 2:1 on the other side, frequently leading to a field road. The channel can be used as a turning area for tractors and machinery. DBLBs must be used on land where the natural gradient in the direction of the supply channel is enough to isolate the irrigations of successive basins (i.e., the difference in elevation between basins must be greater than the difference between water levels when irrigating a basin and when conveying past the basin immediately upstream, plus some freeboard between the upstream basin and the water surface--see Fig. 1). The earthen channel should have some slope in the direction of water flow to assure complete drainage after an irrigation or precipitation event. This will facilitate drying and associated equipment re-entry.

FINDINGS: Level basins are used on about one-third of the irrigated land in Arizona. The Irrigation Management Service teams (mobile labs) have shown in many instances that the performance of level basin systems has not been as high as might be expected, averaging about the same as sloping furrow and border systems. Much of the low performance can be attributed to poor management practices, but in many instances inappropriate design or no design at all may be the culprit. However, intermixed in their results are level systems that perform with high uniformities and on-farm efficiencies. In addition to inappropriate design and management, Mr. Payne identified factors that contribute to slow adoption of level basins when comparing conventional with DBLBs (table 1). The difference in installation and development cost between the two level basin-type systems is significant--ranging from 2 to 3 times more for the conventional system (2.4 times for the comparative numbers given in table 2). Mr. Payne provided a comparison of all production inputs for cotton on two paired fields on a client's farm during 1996, one with 1/4 mile runs with slopes of 0.2'/100' using siphon tubes, the other using high volume turnouts (15 cfs) into 9-acre level basins (gross 1/8 x 1/8 mile) (table 3). In table 3, the net benefits of using the drain-back system are also included using input from the 1997 experience. The resulting net benefits for the conventional level basins versus sloping are significant ($150/ac), with the benefits increasing by $100/ac to $250/ac by using the drain-back system. About 2800 acres of DBLBs have been installed on several farms in Arizona over the last year.

INTERPRETATION: Lower installation and development costs of the DBLB system compared to conventional level basins may become the impetus for further development of level basins, mainly associated with favorable financing with relatively short pay-back periods (e.g., DBLB pay back in about one year--annual net benefit, $250/ac; installation/development cost, $257/ac). Further, the ability to apply smaller irrigation applications will improve the efficiency of the system (smaller early season applications) and the potential productivity associated with small, frequent irrigations. Other advantages include improved machinery efficiency, reduced land loss and simplified weed control, and reduced risk of damage from ponded water. The main limitations of the DBLB system are (1) loss of exact control of the net amount of water applied (i.e., net applied equals gross applied less amount drained off, where the amount drained off is variable depending on the issues noted earlier), and (2) DBLBs must be used on land where the natural gradient in the direction of the supply channel is enough to isolate the irrigations of successive basins.

FUTURE PLANS: The implementation of DBLBs will be monitored. Input on design and management guidelines will be provided as needed, and a "how-to" leaflet will be developed to support implementation of DBLBs in both low- and high-rainfall zones. Operating DBLB systems will be evaluated in the field to assess their performance (e.g., distribution uniformity, net amount applied, etc.) and to obtain a data base for comparison to hydraulic-model-generated performance parameters.

COOPERATORS: Harold Payne, private consultant Higley, AZ; farmers using the drain-back level-basin systems; Natural Resources Conservation Service; and Irrigation Management Service--Mobile Laboratories.

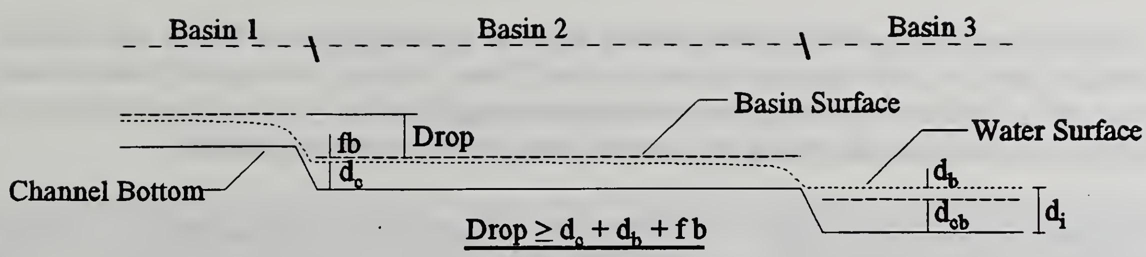

Figure 1. Elevation view showing the conveyance-distribution channel and water surfaces relative to the basin surfaces. In the view, Basin 3 is irrigating (the water is checked-up), with water flowing past the upper two basins. Various dimensions are shown to clarify the amount of drop needed from basin to basin. Definition of terms: d_i = maximum water depth in channel when irrigating, d_{cb} = channel depth, d_b = maximum depth of flow at inlet end of basin, d_c = maximum water depth in channel when conveying, fb = freeboard between the upstream basin surface and the water surface.

Table 1. Comparison of conventional and DBLB systems.

Installation/Development Costs	
Conventional	Concrete lined canal used to convey water to the basins and gates used to turn water into the individual basins increase the cost of this system. Total installation/development cost estimated at $612/ac (table 2).
Drain-Back	Concrete lined canal and gates not needed. Total installation/development cost estimated at $228/ac (table 2).
Financing	
Conventional	Lenders are reluctant to finance improvements requiring long-term pay back, costing nearly 2/3 the value of the land.
Drain-Back	Lower cost makes financing more attractive--1-year pay back.
Water Application--Early Season	
Conventional	Crops require small applications (2 in or less) early in the season, but minimum applications normally are in the 4 to 5 ac-in/ac category.
Drain-Back	Since a portion of the water is drained back (depending on the field conditions, as much as 25% to 45% of the water on the basin or in the furrows at the time the irrigation is changed), early season small applications are possible.
Water Application--Small, Frequent Application	
Conventional	Not possible, still in the 4 to 5 ac-in/ac category.
Drain-Back	Small applications possible; thus, potentially taking advantage of yield increases that come with small, frequent applications--especially as it relates to cotton. A 10% to 15% yield increase would be worth about $100/ac to $150/ac to the farmer.
Machinery Efficiency	
Conventional	Depending on the field configuration, machinery may be limited to the length of run of the basin.
Drain-Back	The water conveyance channel is shallow and wide, allowing machinery to move freely within or through the channel, thus improving the opportunities of increased machinery length of travel.
Land Loss and Weed Control	
Conventional	Significant land loss and increased weed control costs associated with area for roads, ditches, and basin berms.
Drain-Back	Weed control is simplified since elevated, concrete lined ditches are not used.
Ponded Water	
Conventional	Over-irrigation and/or untimely rainfall can cause problems for certain crops (especially alfalfa).
Drain-Back	The drain-back feature protects this system from excess water that might be applied from over-irrigation or untimely rainfall.

Table 2. Installation/development cost comparisons between conventional level basins and DBLBs. The comparisons are based on 1996 construction costs in Pinal County, Arizona, for a typical 10-acre basin (660' x 660' gross, 640' x 620' net) with the conventional basins using a common concrete-lined ditch with basins being irrigated from both sides and using large turnout structures (one turnout per basin).

Conventional Level Basin System	**Cost ($/ac)**	**Drain-Back Level Basin System**	**Cost ($/ac)**
Engineering Cost	6		1
Surveying	10	(GPS system)	4
Ditch Pad Construction (733 yd^3 @$0.50/ yd^3)	40	None	
Road Construction (336 yd^3 @ $0.50/ yd^3)	18	Same as conventional	18
Berm Construction (177 yd^3 @ $0.50/ yd^3)	10	(88 yd^3 @ $0.50/ yd^3)	5
Concrete Lined Ditch (slipformed): (28" deep, 12" bottom, 1:1 side slope, 660 lf x 50% x $5.25 lf)	190	None	
Turnout Gates (one/basin @ $1,250 ea)	137	Structure to drain from one basin to another (30" steel corrugated specially constructed pipe, $259 ea)	28
Earthwork (land leveling, 400 yd^3 /acre @ 0.50/ yd^3)	200	Same as conventional	200
Total Construction Cost	**611**	**Total Construction Cost**	**256**

Table 3. Annual net benefits of conventional and DBLB systems versus a conventional sloping furrow system with siphon tubes.

Item	**Annual Net Benefit ($/ac/yr)**	
	Conventional Level Basins	**Drain-back Level Basins**
Water use reduction (40% or 2.2 ac-ft/ac @ $42/ac-ft)	90	90
Irrigation labor reduction (6 to 2 irrigators)	55	55
Fertilizer reduction	10	10
Yield increase (15% or 225 lb lint @ $0.70/lb)	155	155
Installation/development cost (5 yrs @ 10% interest)	-160	-60
Net Benefits	**150**	**250**

SURFACE IRRIGATION MODELING

T.S. Strelkoff, Research Hydraulic Engineer; and
A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Throughout the irrigated world, water is applied to fields unevenly and excessively, leading to wastage and to pollution of surface and groundwaters. Computer solution of the governing equations with given irrigation conditions allows rapid evaluation of physical layout and operation. Systematic, repeated simulation can lead to design parameters yielding optimum uniformity of infiltrated water and minimum deep percolation and runoff from the end of the field.

Current models of surface irrigation are insufficiently flexible to allow theoretical study of innovative irrigation techniques, and present models are not always able to complete a simulation. Most current models are limited to single furrows, or border-strips with zero cross-slope and a uniformly distributed inflow at the upstream end. But large basins are currently being irrigated from a single inlet. The flow spreads out in all possible directions, and any one-dimensional simulation of the distribution of infiltrated water must be viewed as a very coarse approximation. Also, departures in a basin surface from a theoretical plane influence the flow; with the irrigation stream concentrated in the lower-lying areas, this can significantly affect infiltration uniformity. Only a two-dimensional model can simulate these factors with any accuracy.

While a one-dimensional approach is suitable for furrows, in real situations flows in neighboring furrows of a set are often coupled through common head and tailwater ditches. In some cases, the tailwater from a fast furrow will enter a slower furrow from its tail end and modify its ultimate infiltration profile. To fully appreciate the effects of such coupling, simulation of interconnected multiple furrows is necessary.

The objective of current development is to provide validated simulation models capable of providing quick results for a wide variety of test combinations of design and management parameters.

APPROACH: For one-dimensional single-furrow, border strip, or basin simulation, user-friendly, menu-driven data input and output graphs and text are linked to a simulation engine based on the universal laws of hydraulics applied implicitly in fully nonlinear form over finite time steps to finite volumes of the surface stream and infiltration profile. Constants in commonly accepted empirical equations for infiltration and roughness are entered as input. Program development involves linking FORTRAN and C++ components. Funding for this effort is currently being provided by the Natural Resources Conservation Service.

Two-dimensional simulation is also based on hydraulic principles. Under the assumption of flow velocities small enough to neglect accelerations, force components in each of two mutually perpendicular directions on the field are in equilibrium. The resulting parabolic partial differential equations, solved implicitly by locally linearized finite differences in the two directions and time, yield a wave-like solution encompassing both wet and dry areas of the field. Calculated depths of flow in the nominally dry areas are many orders of magnitude smaller than those calculated within the irrigation stream, making demarcation of a nominal advancing wetting front easy. Infiltration is assumed to begin only after this stream front arrives, and to stop after the calculated depth drops below a specified small value.

A similar approach, treating wet and dry cells uniformly, is applied to multiple coupled furrows.

FINDINGS: A user-friendly, menu-driven, one-dimensional surface-irrigation model with graphical and text output, SRFR, version 3.0, has been released and distributed to cooperating researchers and action agencies. Because the majority of users will not be taking advantage of the program's advanced features (such as spatial and temporal variability of field parameters or dimensionless input and output), a two-tiered, user-selectable pathway to data entry is made available: standard surface-irrigation operation is enabled through a "standard" subset of data-entry screens; "advanced" usage of the program allows the full range of data entry. Complicated input field data can be read from text files. Cablegation and several commercial surge valves can also be simulated.

In the simulation engine, in order to avoid premature calculation of negative depths in the surface stream under conditions of strong infiltration and a relatively thin irrigation stream, the computational grid was made stationary. This avoids interpolation errors in the calculated infiltrated volumes, which cannot be absorbed by a small-depth surface stream without calculating negative depths. An algorithm for front-end recession with the potential for re-advance has been constructed: when front-end recession is calculated, the stream front is held stationary at a location consistent with positive depths in the interior of the stream. Volumes spilled through this front are included as infiltration just downstream. When the rate of spill is sufficient to match predictions by the infiltration formula, the front is once again advanced.

Bottom configuration, infiltration, advance and recession were measured in the irrigation of a large basin in the Gila River Indian Community. The data will be used for irrigation evaluation and testing two-dimensional models of surface irrigation. Results of the Water Conservation Laboratory's zero-inertia basin model were compared to the explicit St. Venant model of Enrique Playan in a moderate sized Spanish basin with varying standard deviation of bottom elevation. Relatively good agreement was obtained for advance and moderate agreement with recession. The zero-inertia model was modified to simulate flow-guiding berms in the interior of basins. These can also be used to provide an irregular outer shape to basins. The model was used to aid in the evaluation of small badly leveled Spanish basins in the province of Jaen. The irrigation stream must flow around the berms, which then play a significant role in the uniformity of infiltration developed (see Fig. 1a, b). The program is also being applied to large Australian basins.

The double-sweep equation solver has been modified to accept unknown discharges at the head and tail ends of coupled furrows or ditches. The result is a set of simultaneous equations, roughly equal in number to the number of nodes and branches. Different solution methods for this non-sparse system are being considered, both direct and iterative. Once the overall system has been solved, depths and discharges in the cells of the individual branches are found sequentially. The mix of wet and dry furrow and drain-ditch sections is ideally suited to the zero-inertia approach with its parabolic partial differential equations.

INTERPRETATION: The response of cooperators to the SRFR data entry screens and graphical output has been positive. The growing body of simulation software is finding users in the national and international irrigation community, for design, management, and evaluation of surface irrigation. It is likely that studies of the interrelationship among distribution uniformity, standard deviation of surface elevations, and inflow rate will provide a useful adjunct to current design software.

FUTURE PLANS: Deficiencies in SRFR noted by cooperators will be addressed, including coalescing of successive surges. The pilot two-dimensional model will be reoriented towards routine application; numerical solution parameters will be adjusted automatically in response to solution behavior. Methods for increasing the allowable time step, currently very small in basins with fine definition of soil and water surfaces, will be explored. The coupled multiple-furrow model will be completed, and additional field verification for both the two-dimensional and the multiple coupled furrow programs will be sought.

COOPERATORS: Thomas Spofford, Natural Resources Conservation Service, National Water and Climate Center, Portland, OR; Enrique Playán, Laboratory for Agronomy and the Environment, CSIC, Zaragoza, Spain; Luciano Mateos, Instituto de Agricultura Sostenible, CSIC, Cordoba, Spain; Hector Malano, University of Melbourne, Australia; D.D. Fangmeier, University of Arizona; Keith Admire, Natural Resources Conservation Service (formerly, SCS), Dexter, MO; Marshall English, Oregon State University; Roger Stone, Gila River Farms, Pinal County, AZ.

REFERENCES: Strelkoff, Clemmens, Schmidt, Dai; 1997, SRFR. Version 3.0

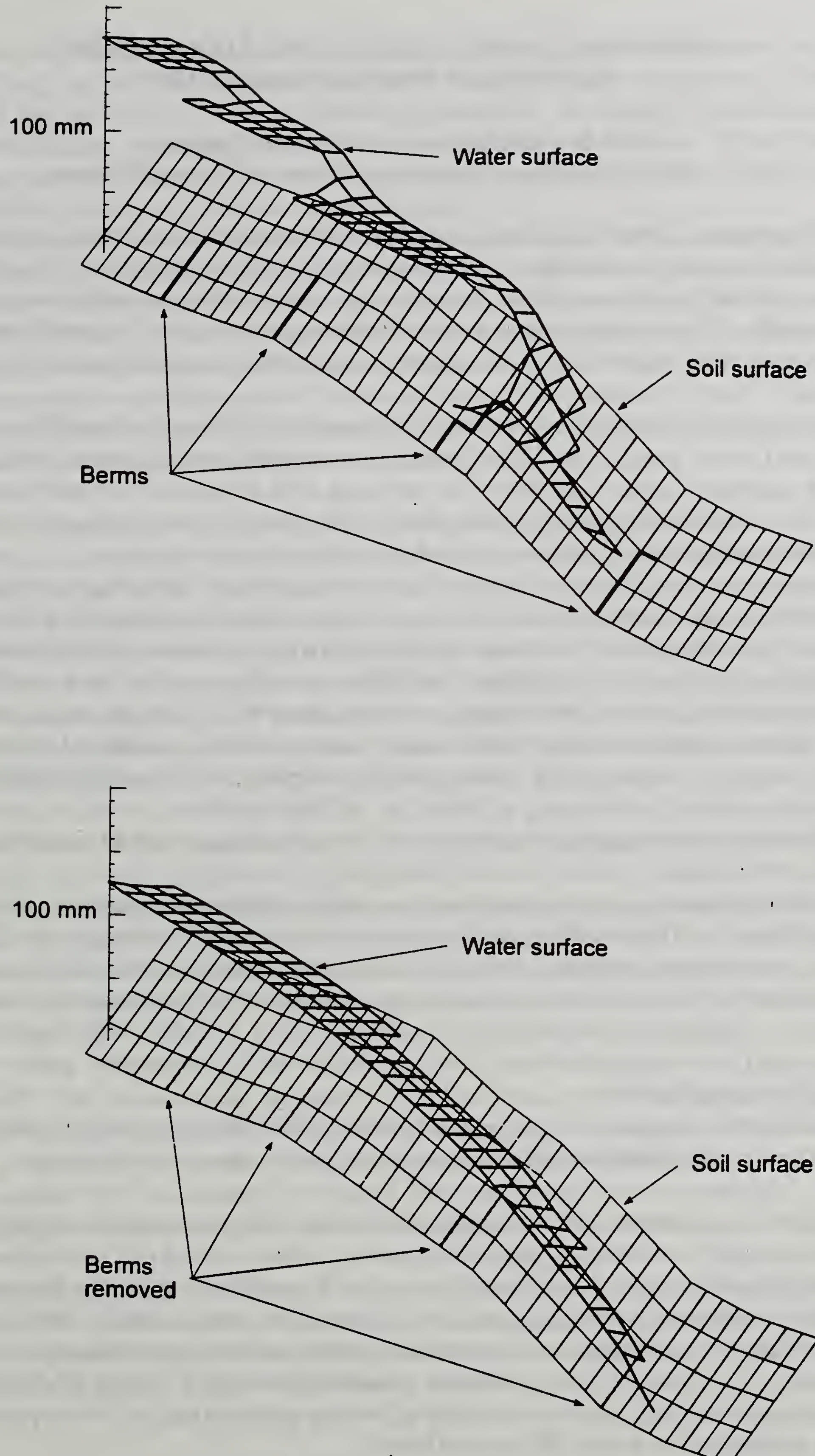

Figure 1. Flow in a poorly leveled basin, with cross slope. At upstream end, far side is 100mm higher than near side. (a) Berms on the low side direct water to the high side. (b) Flow without berms.

SOFTWARE FOR THE DESIGN AND MANAGEMENT OF SURFACE IRRIGATION SYSTEMS

T.S. Strelkoff, Research Hydraulic Engineer;
and A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: In general, surface irrigation is perceived as an inexpensive, low-efficiency method of irrigating crops, bound by inherent characteristics and traditional practices to wasting much, if not most, of the water applied. Furthermore, irrigation water that passes through a farm and discharges into the environment is often chemically changed through contact with soil salts, fertilizers, and pesticides. More efficient irrigation would reduce return flows from irrigation to a minimum and so reduce the potential for contamination of surface- and groundwaters.

Suggested alternatives include conversion to high-tech point application--microirrigation--or simply retiring agricultural land out of production. While limitations on application efficiency do exist, depending upon specific field conditions, current procedures for designing field dimensions and operational parameters are inadequate. Poor understanding of surface-irrigation hydraulics has led to design and management that are largely empirical and greatly dependent on individual judgment and experience.

In recent years, the hydraulic complexity of surface irrigation has been largely overcome through the development of simulation software based on the laws of hydraulics and capable of predicting the performance of an irrigation, given the specific conditions. Infiltration is a major parameter in determining the behavior of a surface-irrigation system; yet its prediction in the field is currently uncertain. Each simulation, taking from a few seconds to several minutes to perform on contemporary PCs, yields the results for just one set of conditions. Before such results can be used in design, some procedure is needed to lead the user from a trial set of design parameters to a better one, in the search for an optimum. A program for design should indicate the best possible potential performance, as limited by the field conditions, as well as how to achieve it. It should also indicate how management could respond to seasonal changes in field parameters, once these are evaluated.

Recently, design and management criteria based on a database of existing simulations have been applied to laser-leveled basins. As a result, efficiency of water application can be achieved at a level approaching that of the more expensive microirrigation. For sloping strips with tailwater runoff, efficiencies of water use are more dependent on field conditions, but rational design, as reported last year, can often substantially improve current practice. Similar procedures for sloping furrows are not yet available. With irrigated farming in many parts of the world under severe economic pressure, attainment of conservation goals without expensive conversions is especially attractive.

The objective of this program is a package of field-evaluation and design software that could be used by designers and technical advisors to irrigators to maximize performance at specific sites.

APPROACH: The performance of an irrigation in a level or sloping field depends on field infiltration, slope, roughness, target depth of infiltration, physical dimensions, inflow rate and application time. The purpose of the software is to provide the relationships for a range of conditions. In earlier approaches, reported in previous years, a large number of simulations is performed, to form a database for the design program. Interpolation in the database allows solution within a continuous spectrum of independent variables.

In the simpler case of level basins, coordinate transformations led to a store of dimensionless data on uniformity, advance time, etc., as functions of unit inflow rate and basin length. From these data, all pertinent performance parameters are derived for any real basin.

In the sloping border case, post-irrigation infiltration profiles and runoff from a multitude of simulations were stored in a dimensionless database. Given a real or hypothetical-design border with all the conditions governing an irrigation known, instead of simulating the irrigation, the commensurate dimensionless input variables are determined for entry into the stored data. Performance (distribution uniformity, runoff, application efficiency, etc.) is derived from the resultant profile and runoff. The calculation is fast enough to yield a whole screenfull

on the variation of performance, as design input varies over a wide range. Such curves show the performance possibilities for the given field conditions and the values of design parameters to achieve a given level.

A limitation of this approach is the finite extent of the database. For example, the database for sloping border strips is insufficient, with a range of moderate slopes and tight soils missing. Without performing the necessary simulations and fitting analytic expressions to the ultimate infiltration profiles to augment the existing database, applicability of the software in this range is limited.

In the current approach, instead of interpolating within a database of existing solutions, fast but very approximate volume-balance solutions with assumed stream geometries could be employed to develop contour maps of performance indicators, showing the dependence of performance on the design or management variables as these are varied over the range of interest, just as in the sloping-border case. The precision of the results, however, is considerably improved by applying corrections derived from one or just a few hydrodynamic simulations centrally located in the design range. This dynamic approach can apply to a far wider range of conditions than one relying on a static database of solutions; e.g., allowing a wider range of irrigation conditions or more complex infiltration equations.

FINDINGS: A Fortran program was written to allow the simulation routines of SRFR to be called repeatedly without its user-friendly data-input shell; that shell is called only once, to specify the field conditions, furrow size and shape, and range of design variables of interest. The simulation provides accurate values of advance time, recession time at the inlet, and the final depth of runoff. Figure 1 shows the design conditions in a given field for a group of simulations constituting a base of exact solutions. Percentage corrections to assumed stream parameters in the volume balances are derived by matching the volume balance solution with the hydrodynamic simulation (see Fig. 2). These corrections are applicable to a range of design variables (Fig. 3), losing accuracy only gradually, with departures from the conditions of the simulation. As the optimum design is approached, additional simulations increase the precision of the results.

INTERPRETATION: There is potential for conserving water and reducing the release of agricultural chemicals into the environment by improved design and management of surface-irrigation systems. Efficiencies can be limited by field conditions, but significant improvement over common current values is feasible. A fast, reliable, user-friendly computer program based on mathematical simulations and showing the response of the irrigation system to variations in trial design conditions should be attractive to potential users, such as mobile evaluation laboratory personnel, NRCS field personnel, extension personnel, consultants, and irrigation district personnel.

FUTURE PLANS: The furrow design program will be fitted into a user-friendly shell and released. The BASIN program will be provided with a component accounting for the influence of imperfect leveling. A similar design program for low-gradient basins is planned. The BORDER Design Aid database of dimensionless solutions will be extended, or replaced with the current dynamic approach. A program for guiding and assisting in the evaluation of field conditions--infiltration and roughness--is contemplated.

COOPERATORS: Thomas Spofford, Natural Resources Conservation Service, National Water and Climate Center, Portland, OR; Emilio Camacho, University of Cordoba, Cordoba, Spain; Harold Blume, Natural Resources Conservation Service, Phoenix, AZ; Kris Johnson, Buckeye-Roosevelt Natural Resources Conservation District, AZ; D.D. Fangmeier, University of Arizona.

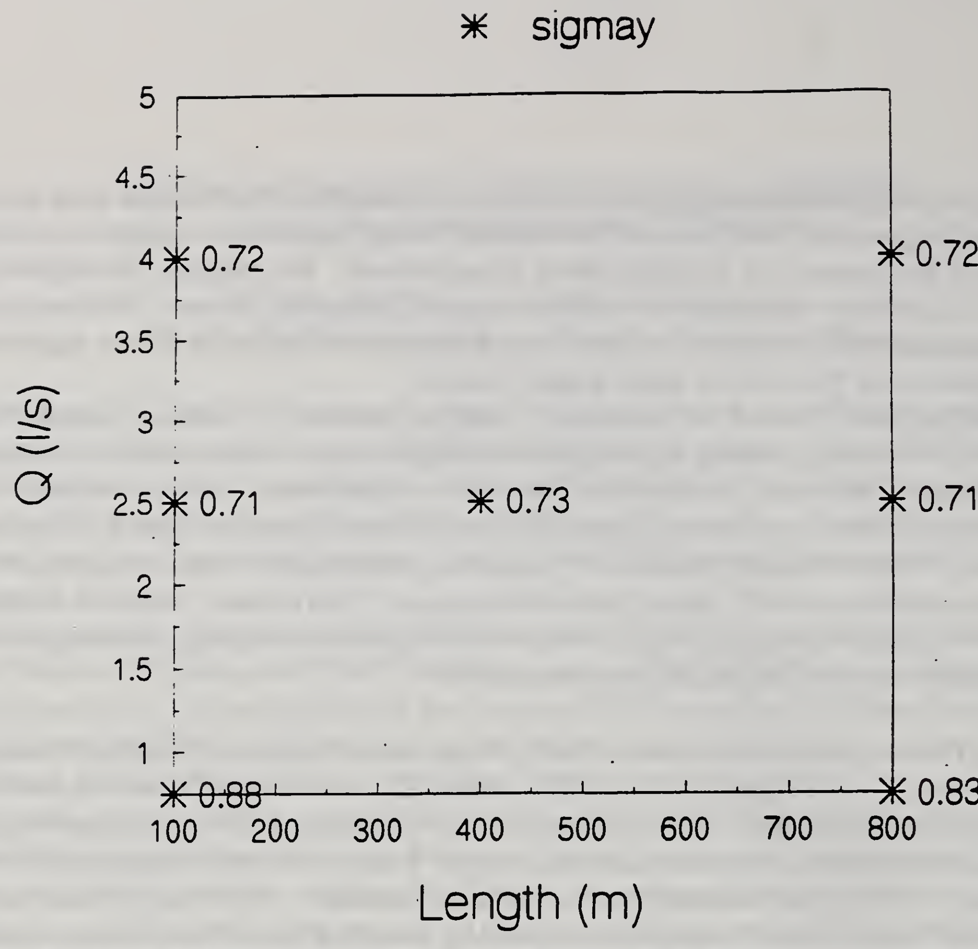

Figure 1. Surface-stream shape factors (sigma y -- to be used in volume balance calculations) at specified values of design parameters: furrow length and inflow rate.

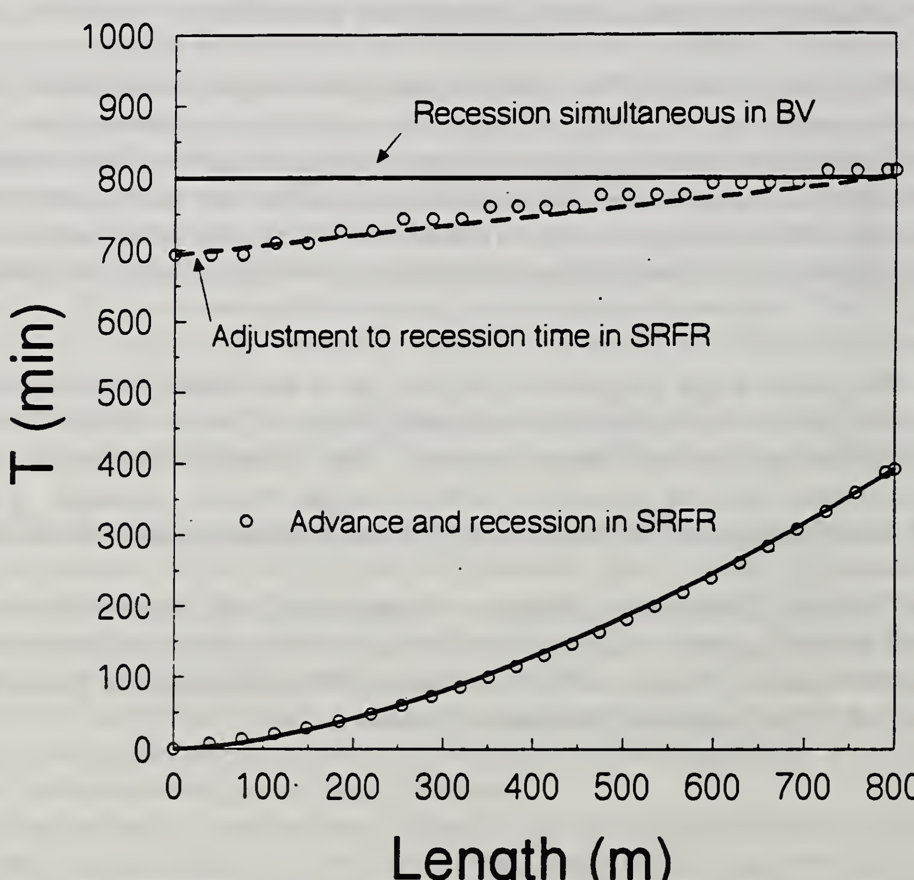

Figure 2. Adjustment of volume balance (BV) parameters to make simplified solution agree with simulation.

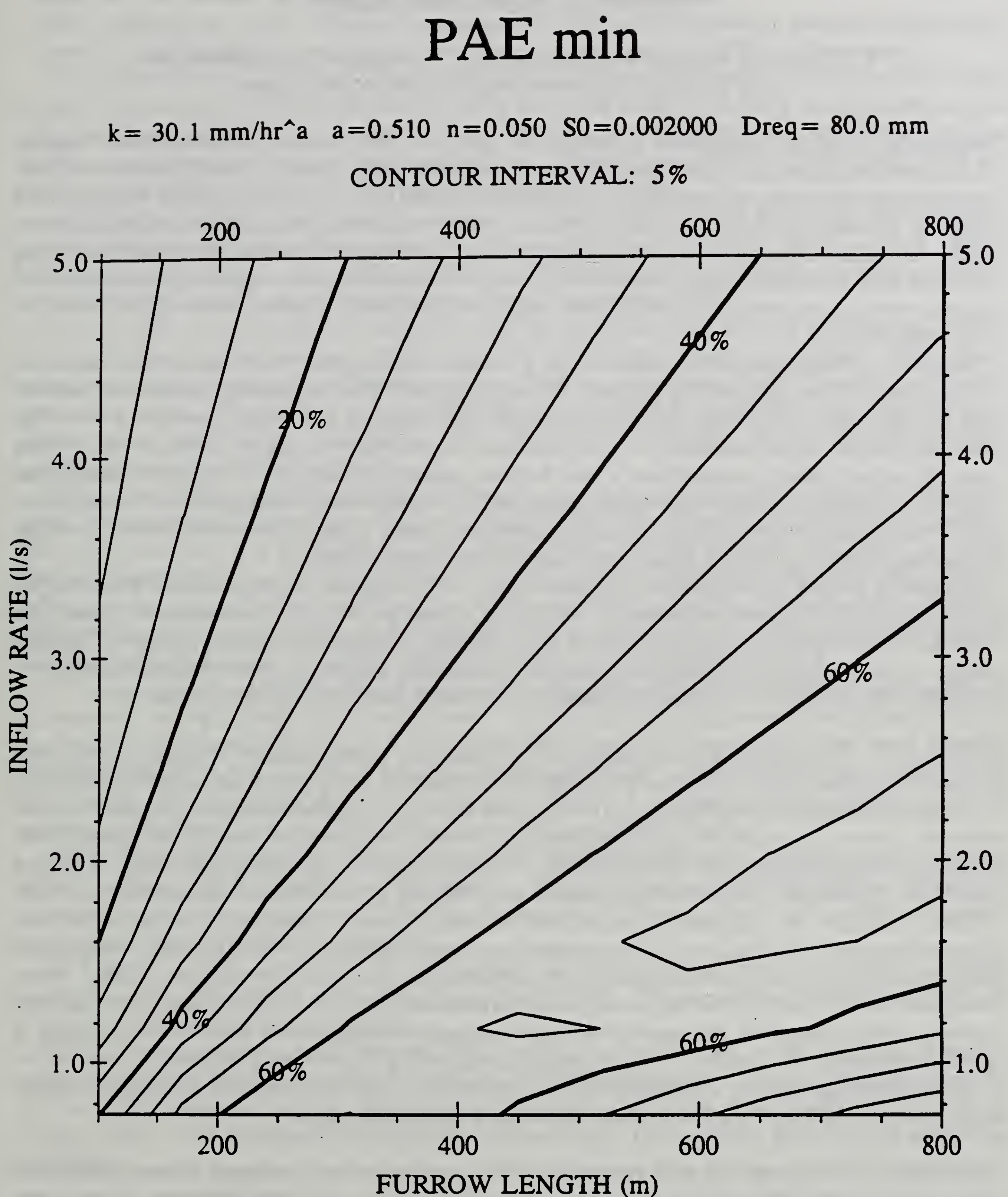

Figure 3. Potential application efficiency -- with satisfaction of infiltration requirement by minimum depth of infiltration -- as a function of design parameters: furrow length and inflow rate.

SIMULATING THE TRANSPORT OF SOIL AND CHEMICALS IN SURFACE-IRRIGATION FLOWS

T. S. Strelkoff, Research Hydraulic Engineer; F. J. Adamsen, Soil Scientist; and
A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Irrigation management influences the quality of both surface and groundwater supplies. Chemigation introduces agricultural chemicals into the irrigation water. Initially clean irrigation water picks up agricultural chemicals and naturally occurring minerals, some toxic, from the surface of fields and from contact by percolation through the porous soil medium. Nitrogen, chlorinated organic compounds, and heavy metals, for example, brought to farm fields in the course of agricultural operations and naturally occurring chemicals, such as selenium, can be transported to surface or subsurface water supplies by the movement of irrigation water, to the detriment both of human consumers of the water resource and wildlife dependent on these bodies of water.

The transport, transformation, and ultimate fate of chemical components of the irrigation water depend on the quantities of water with dissolved chemicals running off the ends of the fields and the quantities of sediment with adsorbed chemicals entering into drainage ditches and canals, as well as the quantities of water that percolate through the soil, entraining or losing chemicals to adsorption on the soil particles, and entering eventually either a groundwater aquifer or a river fed from groundwater seepage. The chemical and physical reactions between the water, the soil medium, and the particular chemicals involved significantly influence the transformation and ultimate fate of the chemical constituents. Sediment discharges can also introduce turbidity into drainage water, deposit in quiescent areas, and reduce field soil fertility.

The goal of the total research effort is a predictive tool; i.e., a computer model, capable of simulating the transport and fate of sediment and chemicals, and thus capable of predicting the environmental response of a given agricultural field and its geologic site to one or another irrigation-management practice. Computer simulations allow comparing various management modes in seeking an optimum. Recommendations could then be made on the basis of environmental considerations and water conservation and crop yield.

APPROACH: The subjects of investigation are: (1) transport of a contaminant by irrigation water from a contaminated soil-surface layer to stream flow and to the groundwater via deep percolation; (2) the distribution of a chemical introduced nonuniformly with the irrigation inflow; e.g., a pulse of chemical introduced at some time after the start of irrigation; and (3) sediment entrainment and deposition in surface-irrigated fields. Chemical and erosion components are envisioned for current surface-irrigation-simulation software. A physical model with a graded sand bed and field experiments are to be used for verification of the mathematical model.

Erosion, transport, and deposition of irrigated soil is a complex matter, impossible to simulate on the basis of general physical principles alone. It is *fundamentally* an empirical science, in which the trend in recent years has been towards evermore general relationships, containing as much general physics as possible. Many conceptual models of parts of the total process have been proposed in order to avoid pure empiricism, but these are only partially convincing and controversial, with researchers leaning toward one or another because of intuitive preferences. The measure of a good predictive relationship or procedure is its generality with respect to different soils and different irrigation conditions, and ability to predict soil transport at different locations in a furrow, especially in the tailwater runoff, at all times during the irrigation.

FINDINGS: In an extension of work reported in 1995, experiments were performed on mass transport of solute between surface flow and soil-pore water in the sand-bed flume, now, with infiltration. Bromide was used as the tracer in two scenarios: (1) The soil profile was saturated with a solution of $CaCl_2$, and a solution of $CaBr_2$ introduced as a surface flow. Solution samples were collected from the soil and analyzed with colorimetry to determine mass transfer of Br from the surface stream to the soil water. Scenario (2) was the reverse of (1); the soil profile was saturated with a $CaBr_2$ solution, and then a solution of $CaCl_2$ was introduced into the surface stream to induce transfer of Br out of the soil profile, in spite of the infiltration. Diffusive mass

transfer of Br in response to concentration gradients between the surface flow and the soil-pore water, were, respectively, additive and subtractive to the convection in the two scenarios.

With funding by the NRCS, and with the assistance of a cooperating institution, Instituto de Agricultura Sostenible, Cordoba, Spain, work has begun on an erosion component for SRFR. Its features are:

(1) Calculation of soil entrainment follows classical lines, assuming fluid shear on the soil surface to be the agent of both bed load and suspended load, the first by direct drag on the soil particles and aggregates in excess of a threshhold, and the second by vertical turbulent mass transfer in opposition to particle fall velocity. No effort is made to separate bed load and suspended load. Observed undercutting of furrow side slopes and subsequent sloughing of soil into the flow are not considered at present.

(2) Differential erosion is acknowledged: much or all of the material scoured at the upper end of the field, where the water is clean and velocities high, can be deposited in the lower portions, where velocities, because of intervening infiltration, are low. While the transported soil might not leave the field, the decreased fertility and, hence, yield, in the upper portions can pose a serious agronomic problem.

(3) To explain observed spatial and temporal variations in sediment concentrations in furrows made of the local soils, the mix of particle sizes and densities in the bed material is taken into account. With particle-size/density fractions responding differently to a given flow, the composition of both the material in transport and in that portion of the bed interacting with the flow changes as the irrigation progresses, and influences further entrainment, transport, and deposition. The total soil mix is subdivided into a number of these groups, and the fate of each is tracked separately.

(4) In a mix of soil groups, the smaller lighter ones are more likely to be eroded by a given flow than larger ones. But entrainment is also influenced by the shielding from the flow of smaller particles by larger particles. The model assumes a well mixed soil layer interacting with the flow and recognizes that only a part of the fraction of small particles in the mix will enter the flow in response to its transport capacity for that fraction; other parts become available to the flow only after larger particles shielding them have been entrained. Furthermore, sorting of sizes leading to a layer of particles or aggregates too large to be entrained on the bed in contact with the flow protects smaller particles beneath from entrainment (armoring).

(5) Local degradation depends both upon local shear, tending to move the bed material, and material already in transport, tending to inhibit further entrainment. Total detachment of all groups taken together is limited by the relationship measured in the local soil between flow shear and entrainment by clean water (potential detachment capacity), and modified by the total current sediment load in ratio to the transport capacity of the flow for the total mix (actual detachment capacity). Further, it is assumed that no particle group will experience detachment in excess of the flow's capacity for transporting that size.

(6) Transport capacity for a mix with a certain median diameter depends upon local shear relative to critical shear and also directly upon particle size and density. Of the several general empirical formulas for transport capacity in the literature, the Laursen (1958) formula was selected because it best fit the envelope of measured transport *vs* shear for the local soils studied.

(7) Sediment loads in excess of the transport capacity deposit on the bed, but not immediately, the delay depending on their fall velocity and median distance from the bed. It is assumed that the largest particle sizes deposit first, followed by the smaller ones.

(8) The field data pertinent to soil transport which must be given to the model are the distribution of particle and aggregate sizes and densities in the soil mix; and, the potential-detachment-capacity function of shear for the soil. With detachment capacity assumed a linear function of shear, the slope (erodibility) and intercept (critical shear) of the relationship constitute the necessary data. The erodibility is found to be mildly time dependent.

FUTURE PLANS: In the coming year, the chloride/bromide exchange experiments will be continued. An erosion component for SRFR should be completed and tested with U.S. and Spanish soils. Simple treatments of chemical transport and fate will be added to SRFR as funding permits.

COOPERATORS: T. Spofford, NRCS, Nat'l Water and Climate Center, Portland, OR; L. Mateos, Instituto de Agricultura Sostenible, Cordoba, Spain; M.L. Brusseau, P.M. Waller, The University of Arizona.

EFFICACY OF CROP MANAGEMENT STRATEGIES AND SOIL TREATMENT METHODS TO CONTROL KARNAL BUNT OF WHEAT

D.J. Hunsaker, Agricultural Engineer; G.L. Peterson, Biologist; F.J. Adamsen, Soil Scientist; and T.A. Coffelt, Research Geneticist

PROBLEM: Karnal bunt (KB) of wheat, caused by the soil and seedborne fungus *Tilletia indica,* is a pathogen of important regulatory significance. In March 1996, bunted wheat seeds were discovered in Arizona and later in Blythe, California, leading to a quarantine of Arizona and Eastern Riverside County, CA, and a number of individual fields outside the regulated area which were planted with contaminated wheat seed from Arizona. Research efforts are needed to develop effective methods to lower the level of the KB pathogen in regulated areas and to prevent the spread of KB to other areas. These include the development of resistant wheat cultivars, equipment and storage facility decontamination methods, seed chemical treatment, soil fumigation methods, and crop cultural practices. The purpose of this study was to determine the effects of soil solarization, several currently labeled soil fumigants, and one experimental chemical, methyl iodide, on the viability of teliospores in the soil.

APPROACH: Studies were conducted during 1996-1997, in Blythe, California on a 5.0-ha field, in which Karnal bunt had been observed the previous season. For all of the following experiments, bunted wheat seeds were obtained from CIMMYT in Mexico and transported to the site under appropriate Federal and State permits. Eight to ten bunted kernels were placed in 50 x 50-mm bags, constructed of 20-υm mesh nylon screen to prevent escape of the pathogen. In August 1996, soil solarization experiments were begun 12 days after the field was flood irrigated. Two solarization treatments and one control treatment were each replicated three times in plots 3.7 m wide by 6.1 m long. For each plot, nine bags of bunted kernels were placed 0.3 m apart, lengthwise along the center of the 3.7-m wide plot, and then buried at three different depths, 5, 100, and 200 mm, such that three bags were buried at each of the three depths. For the solarization treatments, clear, polyethylene tarpaulins were placed over the plot areas and secured. The control treatment was non-tarpaulined. After 30 days, one of the solarization treatments was given another flood irrigation. One bag from each of the three depths was removed from all plots after 30 days. All other bags were removed after 60 days. The bunted kernel samples were transported under appropriate regulatory permits to the ARS, Foreign Disease-Weed Research Unit, Frederick, Maryland, for evaluation.

In October 1996, an experiment with metham-sodium (42.5%) was conducted after the field had been disced and landplaned. Three treatments including two rates of metham-sodium, 185 L ha^{-1} (Low) and 370 L ha^{-1} (High), and one control (no chemical application) were replicated three times in 2.0-m wide plots. For each replicate, nine bags of bunted kernels were placed 0.3 m apart, lengthwise along the middle of the 2-m wide plots, and then buried at three different depths, 5, 100, and 200 mm, such that three bags were buried at each of the three depths. The metham-sodium was applied by shallow shank injection at a depth of 250 mm using four shanks spaced 0.5 m apart. A bed shaper attached to the tractor tool-bar, packed and sealed the soil surface after injection. All bags were removed from the soil 14 days later and transported to Frederick, Maryland, for evaluation.

In February 1997, another experiment was conducted with several commercial soil fumigants and one experimental chemical, methyl iodide. The field was disced and landplaned and then flood irrigated 10 days prior to fumigation. Each treatment was replicated three times in plots 3.7 m wide and 30.5 m long. At 12 m into the length of each plot, bags of bunted kernels spaced 0.3 m apart, lengthwise along the middle of the 3.7-m wide plots, were buried three times each at the 5, 100, and 200 mm depths. Fumigants were applied by shallow shank injection at a depth of 300 mm by Tri-Cal, Inc., Hollister, California.

The following treatments were applied under tarpaulin:

methyl bromide (MB) at 335, 450, and 560 kg ha^{-1} ;
methyl iodide (MI) at 450 kg ha^{-1} ;
chloropicrin (CP) at 335 kg ha^{-1} ;
67% MB mixed with 33% CP at 365 kg ha^{-1} ;
67% MI mixed with 33% CP at 365 kg ha^{-1} ;
Tri-Form CP-15 [80% 1,3-dichloropropene (1,3-D) mixed with 15% CP] at 325 L ha^{-1} ;
Tri-Form CP-30 [66% 1,3-dichloropropene (1,3-D) mixed with 30% CP] at 325 L ha^{-1} ;
control - untreated tarpaulined.

Non-tarpaulined treatments included:

Tri-Form CP-15 at 325 L ha^{-1} ;
Tri-Form CP-30 at 325 L ha^{-1} ;
control - untreated and non-tarpaulined.

Tarpaulins were vented after six days. Bags from all plots were removed 24 hrs later and transported to Frederick, Maryland, for evaluation.

To determine the viability of teliospores, bunted kernels were removed from the bag and teliospores were extracted from the sori. Percent germination was determined after 14 days on 2% water agar.

FINDINGS: Analysis of teliospore germination from samples in the soil solarization and metham-sodium experiments have not been completed. However, preliminary results suggest solarization reduced the viable inoculum.

The mean percent germination of teliopsores analyzed from the soil fumigation study with Tri-Cal are presented for all treatments in table 1. Germination percentages at 5, 100 and 200 mm were not significantly different for any of the tarpaulined treatments. For the non-tarpaulined Tri-Form CP-15 and Tri-Form CP-30, teliospore germination at 200 mm was significantly less than that at 5 and 100 mm at the 0.001 level of significance. Germination means averaged over all depths were not significantly different for those treatments containing either methyl bromide or methyl iodide. However, treatments containing MB or MI had significantly lower germination than all other treatments at the 0.05 level. Treatments with either MB or MI reduced the viability of teliospores at all depths to less than 1.7%. The most effective agent in these tests was methyl bromide, which completely eradicated the pathogen at the 450 kg ha^{-1} and 560 kg ha^{-1} application rates.

INTERPRETATION: Methyl bromide soil fumigation of large contaminated production fields may not be practical or cost effective. However, the application may be useful outside the regulated area to treat small fields inadvertently planted with contaminated seed. Particular attention should be given to methyl iodide, which is currently being considered as an alternative to methyl bromide. Soil solarization may provide an effective non-chemical method for KB control.

FUTURE PLANS: U.S. Conservation Laboratory involvement in KB research is not planned for 1998.

COOPERATORS: Gary L. Peterson, Biologist, USDA, ARS, Foreign Disease-Weed Science Research Unit, Fredrick, MD; Kathy L. Kosta, Pathologist, California Department of Food and Agriculture, Pest Detection/ Emergency Projects, Sacramento, CA.

Table 1. Mean germination of *T. Indica* teliospores after application of soil fumigants.

Treatment	Under tarp	Application rate	Germination (%) by depth (mm)			
			5	100	200	Average
Methyl bromide	Yes	335 kg ha^{-1}	0.6	0.0	0.8	0.4
Methyl bromide	Yes	450 kg ha^{-1}	0.0	0.0	0.0	0.0
Methyl bromide	Yes	560 kg ha^{-1}	0.0	0.0	0.0	0.0
Methyl iodide	Yes	450 kg ha^{-1}	0.6	1.6	0.0	0.7
Methyl bromide(67%)-Chloropicrin (33%)	Yes	365 kg ha^{-1}	0.7	0.3	0.4	0.5
Methyl iodide(67%)-Chloropicrin (33%)	Yes	365 kg ha^{-1}	0.4	0.2	0.4	0.3
Chloropicrin	Yes	335 kg ha^{-1}	12.7	4.2	1.4	6.1
Tri-Form CP-15	Yes	325 L ha^{-1}	24.4	17.8	16.8	20.2
Tri-Form CP-30	Yes	325 L ha^{-1}	33.4	18.3	22.4	24.7
Tri-Form CP-15	No	325 L ha^{-1}	69.8	56.7	20.1	48.9
Tri-Form CP-30	No	325 L ha^{-1}	58.1	27.4	2.4	29.3
Control	Yes	None	64.9	72.9	73.8	70.5
Control	No	None	63.8	61.3	66.0	63.4

WATER PROJECT MANAGEMENT

IRRIGATION FLOW MEASUREMENT STUDIES IN CLOSED PIPE SYSTEMS

J.A. Replogle, Research Hydraulic Engineer; and B.T. Wahlin, Civil Engineer

PROBLEM: Pipe flow problems of current interest include the effects of flap gates on pipe outlets, flow profile conditioning in pipes, and field applications of several flow meters used with irrigation wells.

Flap gates at the end of pipes exert a back pressure into the upstream piping. Whether this back pressure is significant to some applications is questioned by users. The back pressure due do the gate weight and the stiffness of the flexible hinges is not well established.

Most delivery canal systems use pipes through the canal banks to deliver flows to farm canals. Propeller and ultrasonic meters placed in these pipes frequently are subjected to poorly conditioned flow profiles that severely compromise the meter's operation. Methods to condition flows and improve the flow profiles are needed.

Several pipe flow metering devices are limited in their field use when applied to irrigation canals and wells. Propeller meters, end-cap orifices, and Pitot systems are among these. Propeller meters readily clog in debris-laden flows and usually can be inserted into trashy flows for only a few minutes. End-cap orifice meters do not work well on rusted pipe ends.

Pitot systems are considered difficult to apply to irrigation wells without special preparation of the pipe with wall taps and insertion ports. Inserting a standard combination Pitot-static tube such as the Prandtl tube into the outflow end of a pipe has been used (Replogle et al., 1962). However, these Prandtl tubes require specialized manufacturing techniques not available in most machine shops.

The several objectives associated with pipe system flows are to: (a) verify the design and calibration of a modified Pitot system for irrigation wells that can be constructed in ordinary shop settings; (b) complete the data evaluation on the end-cap orifice; (c) evaluate the back-pressure effects of flap gates at pipe outlets; (d) develop practical methods to achieve effective flow conditioning in pipe outlets, and (e) evaluate prototypes of clog-resistant propeller meters that have been manufactured to our suggestions.

APPROACH: (a) To avoid pipe deterioration and probe location problems, a combination system was designed to be inserted into the pipe about one-half pipe diameter. It was made of two easily constructed tubes using standard commercial pipe and pipe parts (Fig. 1). The total head probe traverses the pipe. A static pressure is obtained with a static pressure probe placed against the inside of the pipe wall and is offset to a wall position that was not in the traverse path of the total head probe. The laboratory weigh tank was used to obtain accurate comparison flow rates. Velocity readings across the pipe were obtained using the 10-point method advocated in text books and other references. Tests verified (1) whether the insertion distance was a factor, (2) whether artificial back pressure could be used to provide full pipe flow if needed, (3) whether the Pitot tubes themselves cause significant back pressure, (4) whether pipe roughness influenced results, (5) whether the direction of traverse was significant, and (6) whether field application was practical. All parts were constructed using standard machine shop techniques.

(b) Standard calibration procedures were completed on the end-cap orifice system using the laboratory weigh tank. An alternate pressure tapping system for the end-cap orifice using a small static pressure tube (with holes drilled through its walls) to detect the pressure in the large pipe upstream from the orifice was studied (Fig. 2). The tube was inserted through a grommet-sealed hole in the face of the orifice plate near the pipe wall so that the pressure sensing holes can be positioned one pipe diameter upstream from the face of the orifice.

(c) The flap gate study includes observing the pressure grade line changes with and without the flap gate in place (Fig. 3), and with various weights added to the flap gate.

(d) Methods to condition flow profiles in pipe outlets will include insertion of minimum contraction orifices and sidewall vanes. A special 30-inch diameter pipe facility has been constructed to conduct these tests.

(e) A meter builder (Global Water), in Fair Oaks, California, constructed and furnish two industrial propeller meter prototypes following our debris shedding design proposals. They will be tested in the 30-inch diameter pipe facility mentioned above. An ultrasonic velocity probe will be used to define this flow field.

FINDINGS: (a) Pitot System: The Pitot traverse method that used ten points distributed across a pipe diameter, each point representing 10% of the flow area is valid for the constructed system. It accounted for profile distortion, and roughness changes. Direction of traverse was not significant. Back pressure from the tubing stems was not noticeable when the stems were about one-half diameter or more from outlet pipe end. Insertion up the pipe by as little as one-half diameter was the same as one diameter. Partial outlet blockage to force full pipe flow allows accurate measurements. Probe insertion at the face plane using the combined system was not as accurate as inserting into the pipe even a short distance. Single total-head probes used at the end plane was not consistent.

(b) End-cap Orifice: The orifice system calibrated as expected from theory, and is more repeatable than corner tappings on a pipe of uncertain end quality. The convenience aspects of the system were demonstrated.

(c) Flap Gate: We expected that as the flow in the pipe increased, the change in the pressure grade line should decrease because there would be more kinetic energy used to keep the flap gate open. However, no distinct pattern could be seen from the data. Low flows and high flows produces back pressures on the order of only 4 mm to 6 mm of water column.

(d) Flow Profile Conditioning: Not completed.

(e) Propeller Meter: Not completed.

INTERPRETATION: (a) Pitot System: An alternate portable system that is easily constructed is now available to measure flows from irrigation wells. It can be used when the pipes are too short for orifice meters or propeller meters and the profile is distorted. It can also be used on flows from partly full pipes by causing the pipe to flow full with vertical restrictions on either side of the pipe held in place with clamps. (b) End-Cap Orifice: This version of the end-cap orifice can be installed on well pipe outfalls without any specially drilled holes. The corner tap locations of the original version, which also did not require pipe drilling, are somewhat sensitive to poor pipe end conditions. While this version cannot be used if the pipe is in badly eroded condition, it is somewhat forgiving. The orifice still requires the installation to provide standard lengths of straight pipe from the last pipe bend. (c) Flap Gate: While the analysis is incomplete, preliminary findings are that flap gates cause negligible back pressure on pipelines that are flowing full. The difference between low and high speed flow was not significant.

FUTURE PLANS: (a) Pitot System: Report being prepared. (b) End-cap Orifice: Report being prepared. (c) Flap Gate: More evaluation to try to obtain a better description of hydraulic behavior is planned. (d) Flow Profile Conditioning: Start laboratory study phase and refine test facility. (e) Conduct this study in conjunction with the flow profile study.

REFERENCE: Replogle, John A.; Huggins, L. F.; and Black, R. D. 1962. Discharge ratings of a drop inlet for a small farm pond. Trans. ASAE 5(2):210-211, 217.

COOPERATORS: Maricopa Agricultural Center, Univ. of Arizona (Robert Roth), Wellton Mohawk Irrigation and Drainage District (Charles Slocum), Maricopa-Stanfield Irrigation and Drainage District (Brian Betcher), Global Water (John Dickerman), and Plasti-Fab, Inc. (John Vitas).

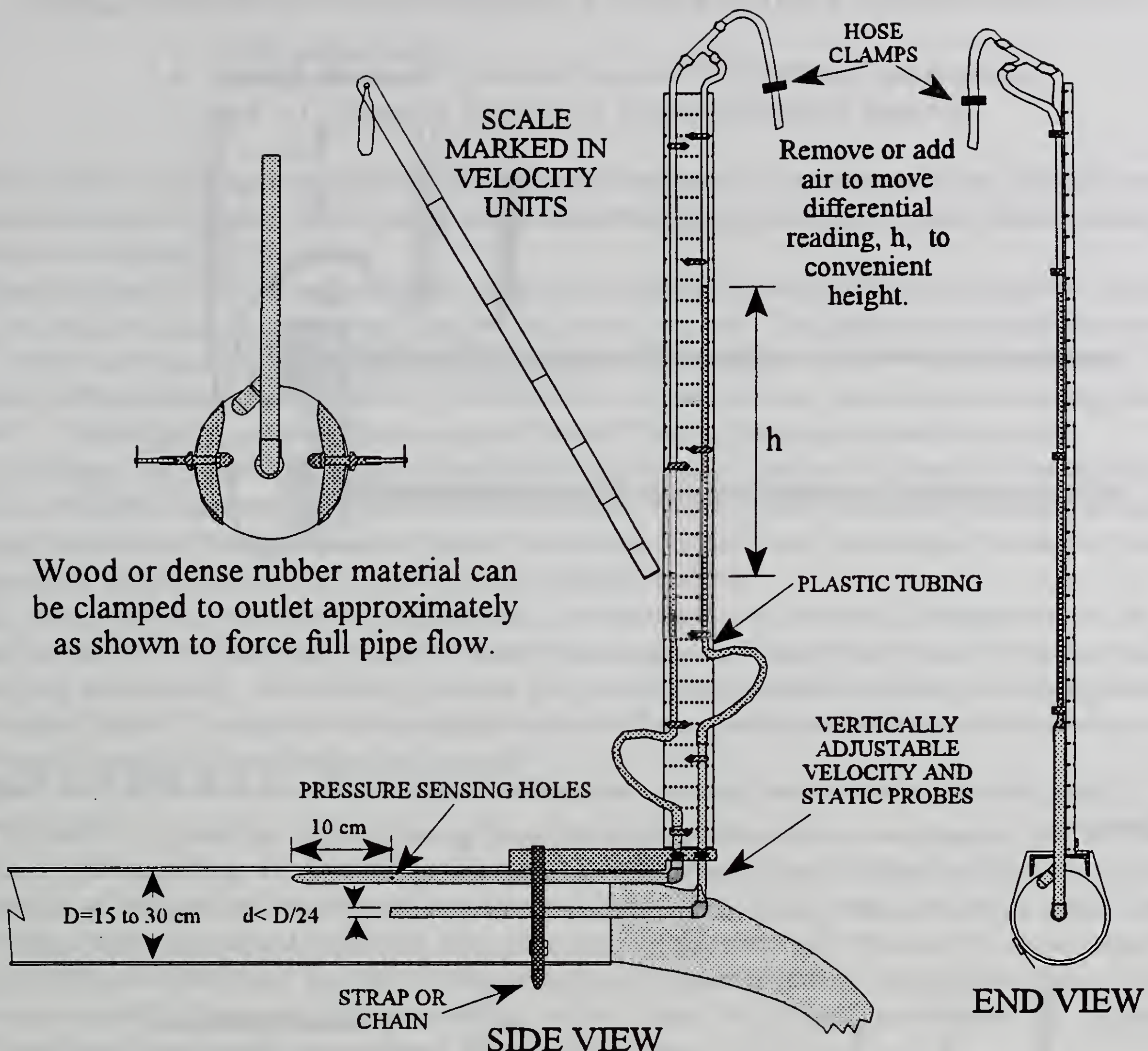

Figure 1. Pitot system for irrigation well pipe outlets.

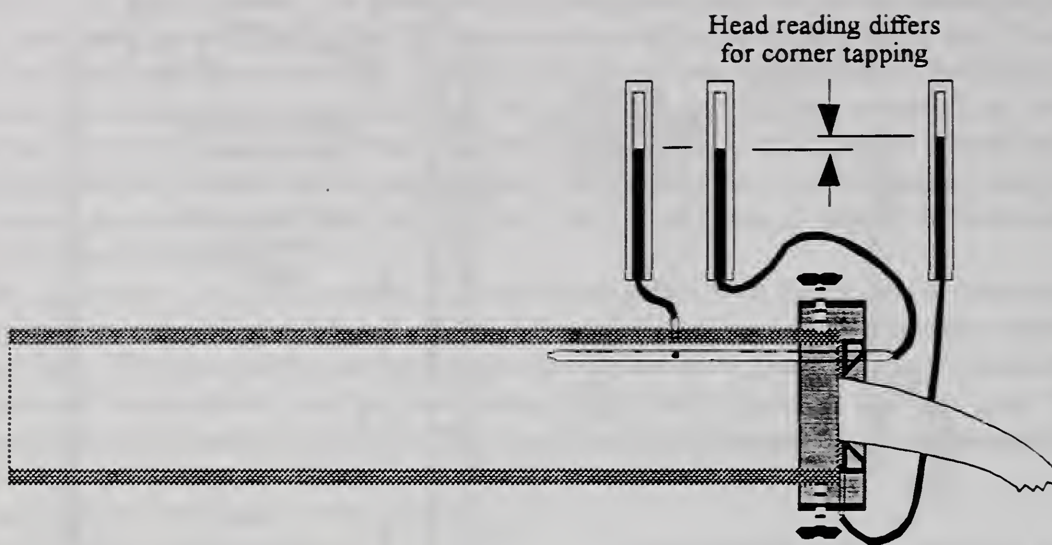

Figure 2. Static pressure probe and wall pressure tap produce similar results, but both differ from flange-tap calibrations.

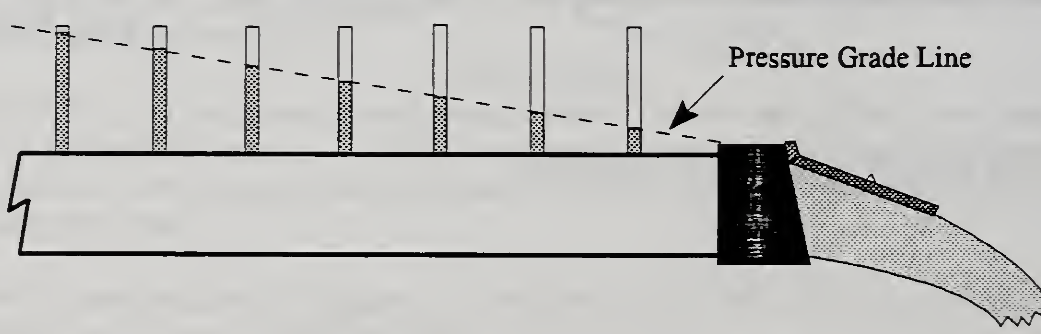

Figure 3. Flap gate on outlet of pipe.

IRRIGATION FLOW MEASUREMENT STUDIES IN OPEN CHANNEL SYSTEMS

J.A. Replogle, Research Hydraulic Engineer; B.T. Wahlin, Civil Engineer;
and A.J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEMS: Discharge measurements in sediment-laden flows in natural streams are difficult because of sediment accumulations. The objective is to evaluate the idea of the self-calibrating flume system and to determine its operational limitations.

Unstable deliveries from a main canal to a secondary canal increase the difficulty of effective irrigation and may require expensive means to monitor total delivery volume. The objective is to develop hydraulic flow control devices applicable where electricity may not be available.

Parshall flumes have been popular flow measurement devices for open channels since their introduction in 1926. Traditionally, problems have arisen in Parshall flumes if they are not constructed to specifications. For example, a large field installed Parshall flume can have a calibration that differs by 10% to 20% from the historical calibrations for that size. The objective is to develop methods to modify wrongly constructed Parshall flumes to recover its function for accurately measuring flow and to identify construction anomalies that can cause large scale calibration shifts.

One of the most important factors in installing a broad-crested weir is vertical placement of the sill. If the sill is too low, the flume may exceed its limit of submergence. If the sill is too high, upstream canal banks may be breached. A movable sill version has become commercially available and is being installed on a limited basis. The objective is to evaluate field installations and assist in design and materials changes that may be needed to hasten technology transfer.

APPROACH: A prototype self-calibrating flume for sediment-laden flows was designed and installed in Northern California (Fig. 1). The design was based on estimated hydraulic behavior of a chute outlet attached to a "computable" trapezoidal long-throated flume. Two stilling wells, one on the main flume, and one on the chute are expected to provide field calibration for the chute after the main flume no longer can function because of sediment deposits. A laboratory model is part of a thesis study at the University of Arizona to check the limits of sediment handling, the best slope for the chute, and whether the calibration of the chute remains stable after the sediment fills the main flume.

A new float-operated valve in combination with a water inflated bag is proposed to be inserted into the pipeline from a main canal to a secondary canal to maintain a desired flow level.

The historical calibrations of a one-fourth scale model of an eight-foot Parshall flume were previously verified. The same model will be fitted with a modified entrance and other changes in an attempt to identify causes of calibration shifts that may be common to many of the large field installations.

Compilation of field experiences by users of the commercialized version of the patented adjustable-sill, long-throated flume will be used to advise on expansion of the product line, and to evaluate field durability and vulnerability to damage from frost and animals.

FINDINGS: The field installation of the self-calibrating flume has experienced difficulties in the instrumentation. An otherwise good calibration flow did not produce a chute calibration because one of the stilling well sensors failed. A second flash flood and a land slide damaged the primary installation. The construction of the laboratory model is progressing well and is on schedule.

Further development of a new DACL (Dual Acting Controlled Leak) valving system was considered after a commercial version did not provide the needed functions. The new valve appears to be capable of all required functions but needs to be laboratory and field proven. A variety of low-cost bag products have been collected. None are yet tested.

A 50-foot Parshall flume calibration, which differs from published calibrations by 10% to 20%, has a modification of the standard rounded entrance into the flume that is suspected of causing the difference. Laboratory model studies to verify this are incomplete.

Field observations and reports have been compiled for flumes ranging in size from 200 gpm to 35 cfs. These are now commercially available under the name "Adjust-a-Flume" (Nu-Way Flume and Equipment Company). Widespread acceptance appears to be growing.

INTERPRETATIONS: The ability to measure flows in heavy sediment carrying flows is important to studies of erosion, runoff, and the effectiveness of best management practices on watersheds. The system, if successful, expands the range and flume shapes available for such use.

Stable flows in secondary canals permits low-cost totalization of flow deliveries to farms because time clocks will suffice instead of complex recorder systems. Stable, constant flows allow more precise management of surface irrigation.

Parshall flumes may not behave as originally specified if modified. While some liberties with the constructed shapes are possible, these need to be clearly identified. One of the most important seems to be the entrance that is frequently modified from rounded shape.

The field problems involving the vertical placement of flumes and broad-crested weirs are greatly reduced for farm-sized earthen channels by the commercialization of a series of semi-portable, long-throated flumes with adjustable throat sills and capacities ranging from 200 gpm to 35 cfs. Sizes above 6 cfs are not intended to be portable.

FUTURE PLANS: The sediment resistant flume in California will be reinstalled. The laboratory model will continue to be designed and built.

The new DACL valve will be laboratory and field evaluated for desired control functions. Further laboratory and field evaluations for function and durability of assembled control systems using the concepts will be reinitiated.

A 4:1 scaled-down model of an eight-foot Parshall flume will be calibrated, modified, and evaluated. Length-to-depth relationships in flumes are to be investigated. The findings for the field installation of the 50 foot Parshall flume will be evaluated on a similar model in the laboratory to determine if the entrance change can cause large scale calibration shifts.

Advice on design changes for adjustable flumes, and evaluation of field performance will continue.

COOPERATORS: Informal cooperation exists between: U.S. Bureau of Reclamation, (Cliff Pugh, Hydraulics Laboratory, Denver); Natural Resources Conservation Service (Harold Bloom); Imperial Irrigation District (Tim O'Halloran); Salt River Project (Joe Kissel, Kirk Kennedy); Wellton Mohawk Irrigation and Drainage District (Charles Slokum), Maricopa-Stanfield Irrigation and Drainage District (Brian Betcher), Buckeye Irrigation District (Jackie Mack); Plasti-Fab, Inc.(Randy Stewart), University of Arizona (Don Slack); California Department of Water Quality Control (Dyan White) and Nu-way Flume and Equipment Company (Charles Overbay).

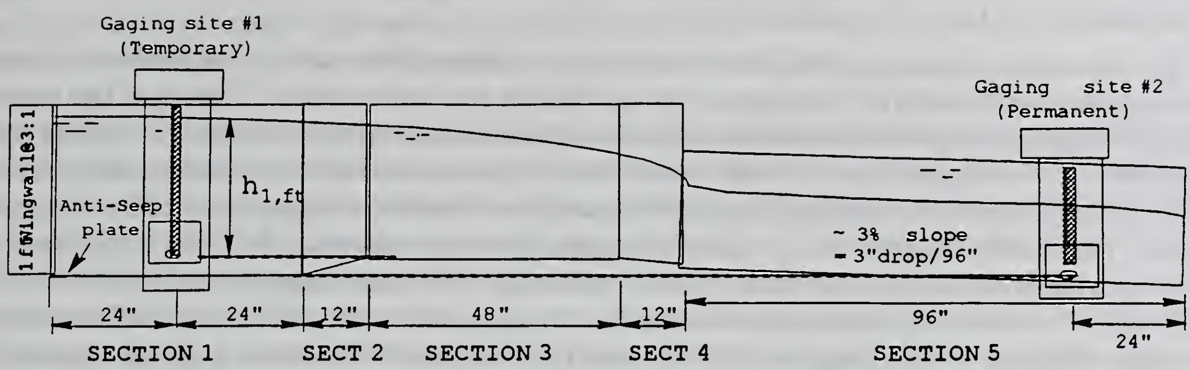

Figure 1. General layout of sediment resistant flume as installed.

WATER REUSE AND GROUNDWATER RECHARGE

H. Bouwer, Research Hydraulic Engineer

PROBLEM: Increasing populations and finite water resources demand more water reuse, as do increasingly stringent treatment requirements for discharge of sewage effluent into surface water. The aim of this research is to develop technology for optimum water reuse and the role that soil-aquifer treatment can play in the potable and nonpotable use of sewage effluent. Present focus in the U.S. is on sustainability of soil-aquifer treatment, particularly the long-term fate of synthetic organic compounds and disinfection byproducts in the underground environment. The fate of pathogens and nitrogen also needs to be better understood. In Third World countries, simple, low-tech methods must be used. Such methods will be applied to demonstration projects in the Middle East and North Africa under the White House Middle East Peace Initiative, the Technology for International Environmental Solutions (TIES) program of USDA and EPA, and the Middle East Regional Cooperation Program (MERC) of USAID in cooperation with the National Research Council (NRC).

Artificial recharge with infiltration basins for storing fresh water underground as part of integrated water management or conjunctive use of surface water and groundwater, or for underground storage and soil-aquifer treatment (SAT) of sewage effluent for water reuse, is still rapidly increasing. The permeable soils that such systems require are not always available, so that less permeable soils like the loamy sands, sandy loams, and even light loams of agricultural and desert areas are still increasingly used to obtain recharge and SAT benefits. Such soils require reliable techniques for infiltration measurements and other pre-investigations to assess the feasibility of the project, and for management of recharge basins to maintain maximum infiltration rates.

Long-term effects of irrigation with sewage effluent on soil and underlying groundwater must be better understood so that future problems of soil and groundwater contamination can be avoided. Potential problems include accumulation of phosphate and metals in the soil and of salts, nitrate, toxic refractory organic compounds, and pathogenic micro-organisms in the groundwater. Water reuse is a good practice, but it should not ruin the groundwater. Long-term salt build-up in groundwater will also occur in groundwater below any irrigated area (agricultural or urban), regardless of the source water, if there is no drainage, groundwater pumping, or other removal and export of salt from the underground environment. Groundwater levels will also rise, which eventually requires drainage or groundwater pumping to avoid waterlogging of surface soils and formation of salt flats. In urban areas, such groundwater rises will damage buildings, pipelines, landfills, cemeteries, parks, landscaping, etc. The salty water removed from the underground environment must be properly managed to avoid problems. Stream depletion by groundwater pumping and solving conflicts between users of surface water and groundwater continue to be a challenge in many parts of the world.

APPROACH: Technology based on previous research at the USWCL and more recent research are applied to new and existing groundwater recharge and water reuse projects here and abroad. Main purposes of the projects range from protecting water quality and aquatic life in surface water to reuse of sewage effluent for nonpotable (mostly urban and agricultural irrigation) and potable purposes. A Southwest regional project has been developed to get more information about fate of synthetic organic compounds, nitrogen, and pathogens in the underground environment so that projects can be designed and managed (including optimum pretreatment) to achieve desirable results, especially for potable use of the water from the aquifer. The project will be set up for about four years and involves six existing field systems in Arizona and California, four universities, numerous water districts, municipalities, and other participants and sponsors. Long-term effects of sewage irrigation on soil and groundwater will be studied in a cooperative project with Arizona State University funded by the U.S. Army Garrison at Fort Huachuca, AZ, using the Fort's golf course that has been irrigated with Army sewage effluent for about 30 years. Laboratory studies will also be performed using 8 ft soil columns and various irrigation efficiencies, including a low efficiency to simulate replenishment irrigation. Various scenarios of rising groundwater levels and salt buildups due to irrigation were analyzed to get an idea of rates of rise in groundwater levels and salt contents of the upper groundwater, and how to handle this water (disposal in salt lakes, sequential irrigation of increasingly salt tolerant crops ending with halophytes to

concentrate the salts in smaller volumes of water), membrane filtration to remove the salts and allow municipal or agricultural use of the water, and disposal of the reject brines.

The validity of legal concepts to resolve conflicts between uses of surface water and groundwater has been tested against the real effects of groundwater pumping on streamflow obtained by analyses of underground flow systems for different conditions of hydrology.

FINDINGS: Field and laboratory tests continue to show the usefulness of recharge and soil-aquifer treatment in water reuse. Main issues still are sustainability of soil-aquifer treatment and fate of recalcitrant organic compounds. Simplified procedures have been developed for cylinder infiltrometers to predict large-area, long-term infiltration rates from short-term tests with single cylinders. In field tests, good agreement was obtained between infiltration rates calculated from cylinder infiltrometer data and infiltration rates from 40 x 75m basins; i.e., 40 cm/day and 32 cm/day, respectively. Also, simplified equations have been developed and applied to predict long-term groundwater mound rises in recharge areas for long-term underground storage of water ("banking") and where to locate groundwater recovery systems to prevent water logging in these areas. The various hydrologic scenarios of stream and groundwater interactions have been analyzed to identify the conditions where groundwater pumping will cause stream depletion, and where not. These conditions must be considered by the legal system when adjudicating surface water and groundwater rights and solving issues of conflicting uses of both waters.

INTERPRETATION: The developments of better technologies or concepts for predicting infiltration rates with cylinder infiltrometers, estimating volumes of water that can be stored underground for water banking, and managing relatively fine textured soils to achieve maximum infiltration for recharge will extend the use of artificial recharge of groundwater to "challenging" soil and aquifer conditions. This will enable water resources planners and managers to benefit from the advantages that artificial recharge offers in conjunctive use of surface water and groundwater, in water reuse, and in integrated water management. Also, the development of basic relations between groundwater pumping and depletion of streamflow will enable the legal profession to develop rules and regulations for conjunctive use of surface water and groundwater that are based on sound hydrologic principles.

FUTURE PLANS: These plans primarily consist of continuing existing research and of developing new research projects, mostly with universities and water districts, on long-term effects of irrigation with sewage effluent on soil and groundwater (field and laboratory studies), salt and ground water management in inland areas with water and salt imports but no exports, control of bio-clogging of recharge wells or trenches by super disinfection of water entering the well and creating a permeable biofilm or bioreactor zone at some distance from the well, and management of clogging layers in infiltration basins to obtain treatment benefits from the clogging layers while avoiding drastic reductions in infiltration rates, and installing infiltration test plots to verify concepts of recharge basin management developed for finer textured soils where clogging, crusting, fine particle movement or wash-out wash-in, hard setting, and erosion and deposition can seriously reduce infiltration rates. In addition, there will be the usual technology transfer and professional society activities.

COOPERATORS: Martha Conklin, Assistant Professor; L.G. Wilson, Hydrologist; Robert Arnold, Associate Professor; C. P. Gerba, Professor; Kevin Lansey, Assistant Professor; David Quanrud and Katanya Miles, Research Assistants; University of Arizona; Sandra Houston, Associate Professor; Peter Fox, Assistant Professor; and Peter Duryea, Research Associate; Arizona State University.

PHYSICAL, CHEMICAL AND BIOLOGICAL CHARACTERISTICS OF A SCHMUTZDECKE: EFFECTS OF SEEPAGE AND WATER TREATMENT IN WASTEWATER DISPOSAL FACILITIES

H. Bouwer, Chief Engineer

PROBLEM: Soil clogging occurs during artificial recharge and effluent disposal operations. Reduced infiltration and consequent ponding are largely attributed to development of a slime layer or "schmutzdecke." The objectives of this project are to determine: (1) physical, chemical, and biological processes occurring in the schmutzdecke, (2) improvement of water quality after it has moved through the schmutzdecke (for example, effect of schmutzdecke on pathogen removal or nitrogen speciation), (3) how schmutzdecke should be managed for specific needs (in particular, to evaluate how schmutzdecke affects flow of essential nutrients: nitrogen, phosphorous, and potassium), and (4) how hydraulics affect schmutzdecke.

APPROACH: Operation of The University of Arizona soil columns and Arizona State University compressibility studies were concluded last year. Activities this year included preparation of the final project report and additional analyses on data collected during the last four years of this study. Included here are new results from The University of Arizona studies: the effect of pre-ozonation of secondary effluent during passage through schmutzdecke and effect of low-ionic strength synthetic rainwater on virus desorption. These were done in one-meter columns containing Agua Fria sand. Unchlorinated secondary effluent was applied to columns in alternating (7 day wet/7 day dry) cycles.

FINDINGS: **Pre-ozonation Studies**--Research objectives were to determine the potential benefits of ozonating wastewater effluents prior to their infiltration. Secondary effluent was obtained from the Roger Road Wastewater Treatment Plant in Tucson, Arizona, and initially ozonated at a level of 1 part O_3 transferred per part dissolved organic carbon (DOC) (mass basis), then levels were reduced to 0.5 O_3 to DOC and 0.25 O_3 to DOC on a part for part basis. Soil-aquifer treatment (SAT) was simulated using both one-meter columns and small (250 mL) batch reactors. One-meter columns containing sand from the Agua Fria River near Phoenix, Arizona, were used to simulate percolation of wastewater through biologically active surface soils (schmutzdecke). Column residence times were typically 3-15 hours. Ozonation effects were determined by comparing treatment efficiencies to a control 1-m column receiving unozonated secondary effluent. Dependent variables included DOC (including degradable and nondegradable fractions), absorbance of UV light, and trihalomethane formation potential (THMFP). Ozone pre-treatment promoted greater removals of organics during passage through a 1-m column. At a dosage of 1 mg O_3/mg DOC, removal of DOC and UV-254 in a 1-m column increased by approximately 30%, and THMFP removal increased by 38%, relative to a control column receiving unozonated secondary effluent. At a dosage of 0.5 mg O_3/mg DOC, a 23% greater removal occurred for measured organic parameters. The final dose of 0.25 mg O_3/mg DOC achieved a 6-7% greater reduction in DOC and THMFP, relative to the unozonated control column. Biodegradable dissolved organic carbon (BDOC) tests were performed in small batch reactors (under aerobic conditions) to measure degradation occurring over a time scale of five days, simulating the degradation expected to occur on the larger time scales typical of percolation through an extensive vadose zone. Levels of DOC remaining at the end of the 5-day batch test were not significantly different (3.2-3.5 mg DOC/L) for ozonated and non-ozonated secondary effluents (Fig. 1). At the highest ozone dosage tested (1 part O_3 per part DOC), the UV-254 of post-BDOC water was 17% lower than for unozonated effluent, but THMFP values were not significantly different (110-125 μg/L).

Virus Desorption Studies--Using 1-m columns operated in parallel, the scenario of rainwater infiltration at a recharge basin and its effect on virus (coliphage) transport was simulated. Significant detachment of indigenous wastewater coliphage was observed during the application of low-ionic strength artificial rainwater (Fig. 2). Ionic strength was isolated as the cause of coliphage release, since no viruses were observed in the effluent during the application of similar high-ionic strength water. Phage desorption was not promoted by solution pH, since the rainwater in this experiment had a lower pH than secondary effluent.

INTERPRETATION: **Pre-ozonation Studies**--These tests indicate that ozone is not effective at increasing the ultimate biodegradation potential of secondary effluent during soil-aquifer treatment. When compared to the column results, where ozone did increase biodegradation, these results suggest that ozonation increases the rate of DOC degradation. From a management perspective, ozonation would not provide additional biodegradation of organics for time-scales expected during vadose zone transport.

Virus Desorption Studies--Ionic strength of the solution was the cause of phage detachment when applying low-ionic strength water to columns previously flooded with coliphage containing water. Significant virus desorption and transport can occur in SAT soils subjected to severe rainfall infiltration events.

FUTURE WORK: Work to be performed includes additional analyses of data collected concerning temperature effects on SAT efficiency and completion of the final project report.

COOPERATORS: Martha Conklin, Associate Professor; L.G. Wilson, Hydrologist Emeritus; Robert Arnold, Professor; C.P. Gerba, Professor; Kevin Lansey, Associate Professor; and David Quanrud, Sean Carroll, John Hillman, Research Assistants, University of Arizona.

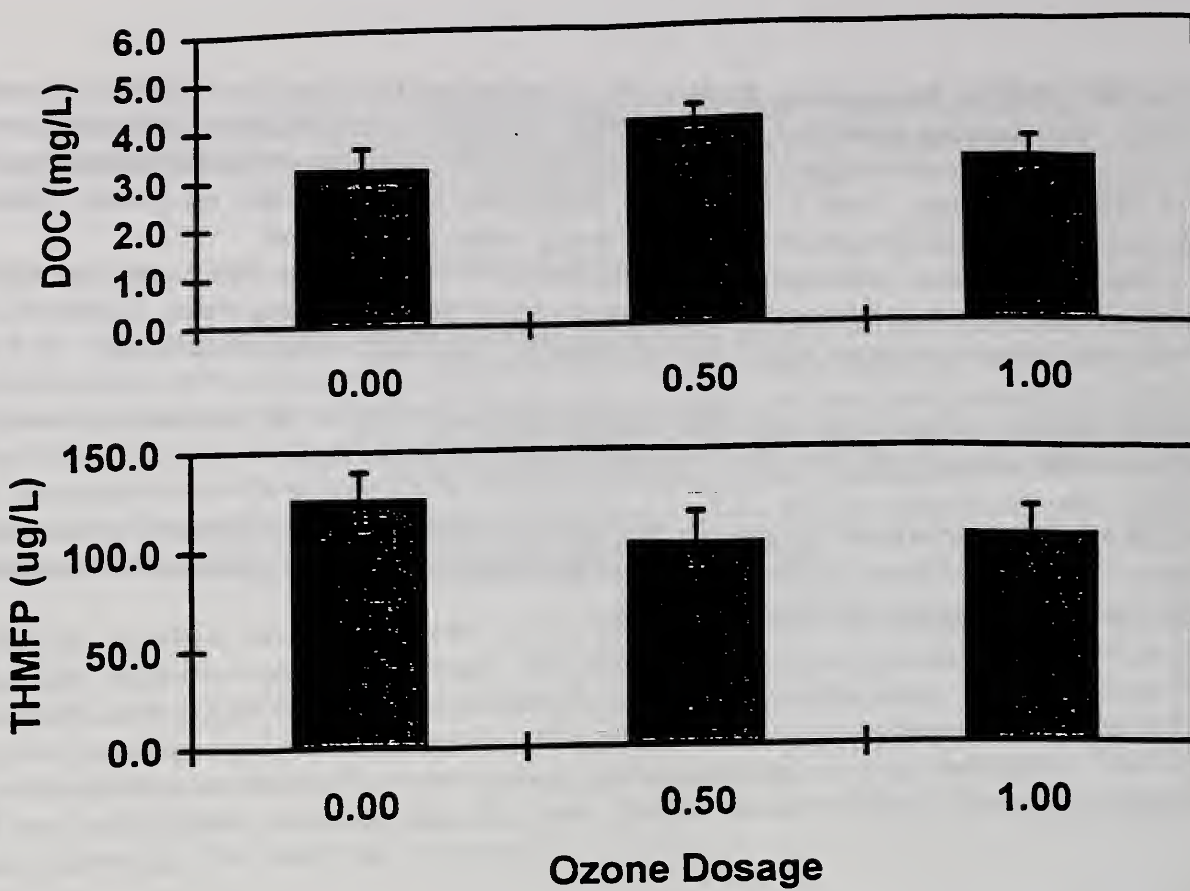

Figure 1. Post BDOC treatment levels of DOC and THMFP as a function f pre-ozonation dosage (parts ozone transferred per part DOC).

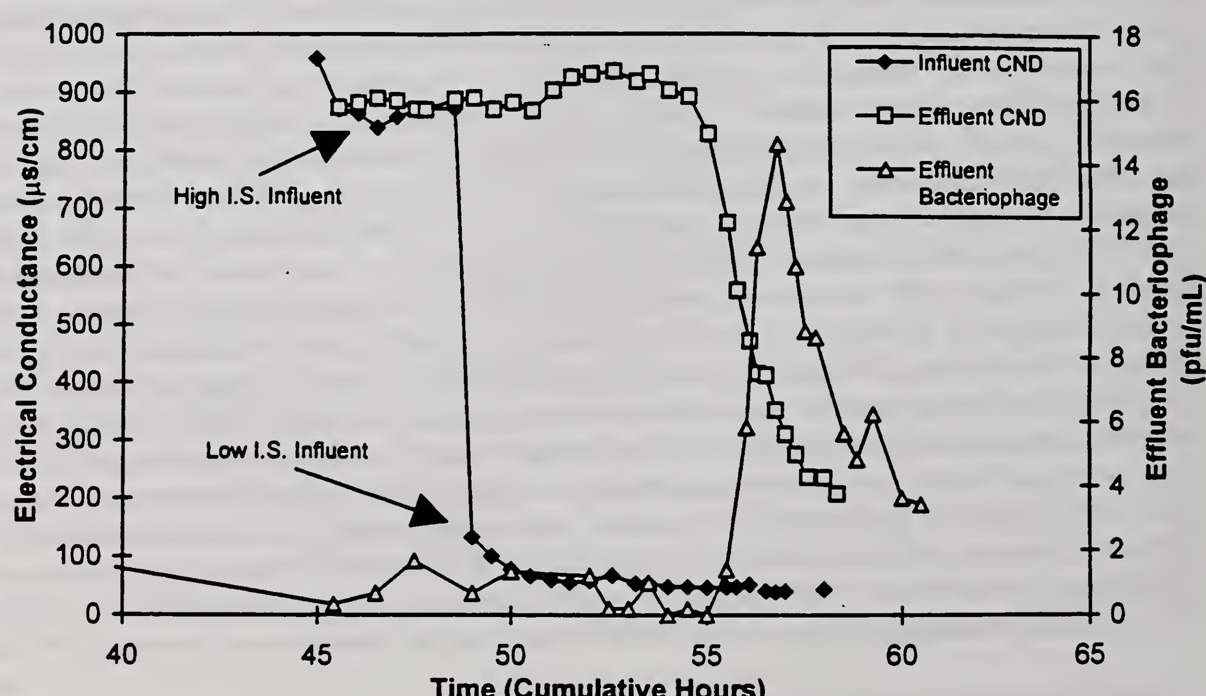

Figure 2. Coliphage (MS-2) desorption during infiltration of low ionic strength synthetic rainwater (CND = electrical conductivity).

MANAGEMENT IMPROVEMENT PROGRAM (MIP) FOR NATURAL RESOURCES

A. R. Dedrick, Supervisory Agricultural Engineer; E. Bautista, Agricultural Engineer;
S. A. Rish, Program Analyst; and A. J. Clemmens, Supervisory Research Hydraulic Engineer

PROBLEM: Enhanced long-term management of water and other natural resources, grower profitability, and overall social well-being are essential to a sustainable irrigated agriculture. Because approaches to these objectives are often uncoordinated, all agricultural stakeholders--farmers, irrigation districts, other support and regulatory organizations, and other interested parties--need to interact proactively to address these needs. [3] To this end, the Management Improvement Program (Fig. 1 depicts the three-phased MIP process), a management process similar to those used to improve the performance of corporate organizations, was applied to the business of irrigated agriculture. The purposes of this research were 1) to develop, apply, and refine for future use the MIP methodology; and (2) to establish conditions in the MIP application area for the continued improvement of farming practices and support services provided to farms by the district and other irrigation-related agencies while conserving related resources.

APPROACH: In December 1990, under the direction of the U. S. Water Conservation Laboratory (USWCL), an Interagency Management Improvement Program (IMIP) was initiated by six agencies[4] interested in the potential of the MIP to support improved irrigated agricultural productivity, profitability, and natural resource management. From April 1991 to January 1994, a demonstration project was carried out in the Maricopa-Stanfield Irrigation and Drainage District (MSIDD) in central Arizona (Fig. 2 is a schematic representation of participating entities). In January 1994, the MIP Team[5] ended its formal leadership of the Demonstration MIP, and a local, grower-led, grower-interagency MSIDD MIP Coordinating Group (CG) assumed ongoing responsibility for future MIP initiatives in the MSIDD area. A formal evaluation of the MSIDD-Area MIP was completed and the report[6] published in October 1994. The following activities occurred during FY 1997. (See "Annual Research Reports," 1991 through 1996, for earlier activities and MIP milestones.)

(1) MSIDD MIP Coordinating Group. (a) Now in its fourth year, the CG is being led by its third grower-leader, who took office in January 1997. (b) The CG held two town-hall-type meetings: a "Finance Forum," featuring speakers from primary agricultural lending institutions in the area and an update on the irrigation district's and area's financial outlook; and a "Production Alternatives Town Hall," with presentations on alternative crops, the farm as an enterprise, and other agribusiness perspectives. (c) The CG continues to publish newsletters and hold grower-to-grower meetings. (d) The MIP Team continued in a consulting role to the CG.

(2) Potential Reapplication of the MIP. (a) Discussions were held with the Resources Development Committee of the Colorado River Indian Tribes (CRIT) relative to an MIP application to support and guide long-term development of CRIT lands. Discussions were begun in 1995 with an irrigation district in Texas, and the area continues to be a potential site for an MIP application. In both cases, funding for the necessary feasibility assessment is an obstacle. (b) Representatives of NRCS and USBR in California have asked to visit

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[1] Two recent prestigious reports stress the need for multi-institutional and other stakeholder cooperation at the local level to deal with complex natural resource management issues: *A New Era in Irrigation, 1996,* the National Academy Press; and *Future of Irrigated Agriculture*, 1996, CAST.

[2] These agencies are USDA-ARS and -NRCS; USDI-USBR; AZ Depts. of Water Resources and Environmental Quality; and The Univ. of AZ Cooperative Extension. They, along with the AZ Dept. of Agriculture and The University of AZ College of Agriculture who joined later, comprise the general oversight IMIP Coordinating Group.

[3] The demonstration project MIP Team included Dedrick, Bautista, and Rish of the USWCL; and consultants W. Clyma (MIP Specialist) and D. B. Levine (Management/Team-Building Specialist). The MIP Team provided overall management of the demonstration activities, which included the direct development and facilitation of MIP events. In addition, the Team maintained ongoing communication with participants, addressed concerns and problems as they arose, and was responsible for the development and publication of MIP-related documents.

[4] *The Evaluation Report of the Demonstration Management Improvement Program in the Maricopa-Stanfield Irrigation and Drainage District Area*, U. S. Water Conservation Laboratory. (Hereafter referred to as *Evaluation Report*).

the USWCL in January 1998 to discuss a possible MIP application. (c) A grant proposal was submitted to the CSREES RFP, "Fund for Rural America," to support feasibility assessments of potential MIP applications.

(3) Publications and Presentations. (a) Five papers are being prepared for a technical journal series. One has been submitted and accepted, and the others are in various stages of completion. (b) A seminar focusing on the MIP was presented to the ARS National Program Staff. (c) The MIP was nominated and unanimously selected as number one from among 33 projects nominated in the west for presentation at a workshop organized by the Charles Valentine Riley Memorial Foundation (RMF). The workshop, held in Reno in November 1997, was one of four held across the U. S., co-sponsored by ARS, NRCS, CSREES, EPA, and several private organizations, in cooperation with the Land-Grant Universities. The workshops examined the characteristics of programs that have succeeded or have the potential for succeeding in building broad-based coalitions and partnerships. The MIP presentation was done by a panel of MSIDD MIP participants: Al Dedrick, ARS; Ralph Ware, NRCS; Tom Burbey, USBR; Jack Watson, University of Arizona Cooperative Extension; Van Tenney, former general manager of MSIDD (now GM, Glenn-Colusa Irrigation District in California), and Karen Ollerton, MSIDD-area grower and past president of the MIP CG. (A video of the MIP presentation in Reno is available.) The four workshops culminated in a workshop at the agency/department level in Washington on December 10. The MIP was chosen for presentation at the DC workshop from among the Western Regional projects presented in Reno.

FINDINGS: As noted above, the CG has continued a number of effective, ongoing functions. Representatives of the MIP Team plans to attend the January 1998 CG meeting to review with them progress on action items identified at the 1996 formal CG Program Review and Planning Meeting. In the past year, representatives of a number of key organizations have left the positions designated for CG membership, and efforts are underway to identify and to bring the new representatives onboard. The Phoenix Area Office of the U. S. Bureau of Reclamation continues to provide financial support for CG operations. Continuing interest in exploring the feasibility of an MIP application was expressed by CRIT, USBR, and the Texas irrigation district in letters of support for the "Fund for Rural America" grant proposal.

INTERPRETATION: The MIP stood out as sharply different from the other three cooperative projects presented at the RMF Western Regional Workshop. The MSIDD-Area MIP is first, a *process*, and second, a *project*. Whereas the other presentations were site-specific, undertaken to address particular situations, the purpose of the MIP, as indicated earlier, was to test the MIP *process* as a way of making and managing change. Testing the process required that it be applied, and the *project* in the MSIDD area was the result. Therefore, while the characteristics of successful cooperative efforts may be inferred from individual projects, those characteristics are made explicit in a strategically planned process. In the case of the MIP, the *Evaluation Report,* in describing what worked well and what needs strengthening, characterizes a refined process that can be applied broadly to complex natural resource situations involving multiple stakeholders.

The MIP participants who presented at the RMF Workshop provided vivid, insightful perspectives from the standpoint of their agencies, themselves personally, and associated impacts. Keeping in mind that the RMF presentation was almost four years after the formal closure of the demonstration, it was clear that their involvement in the MIP is causing them to do business differently.

FUTURE PLANS: The research phase of the MIP has essentially been completed. Work will focus on documentation of the Demonstration MIP, including completion of a paper series for a special issue of *Irrigation and Drainage Systems Journal (IDSJ)*. The Evaluation Report, together with the *IDSJ* series, can substantially guide future MIP applications. Members of the MIP Team will be available for consultation. The implications of the MIP presentation at the RMF workshop in Washington are unclear at this time.

COOPERATORS: Cooperators include entities in figure 2, plus Colorado State University. Funding has been provided by ARS, USBR, NRCS, and ADWR; with significant in-kind contributions by all involved.

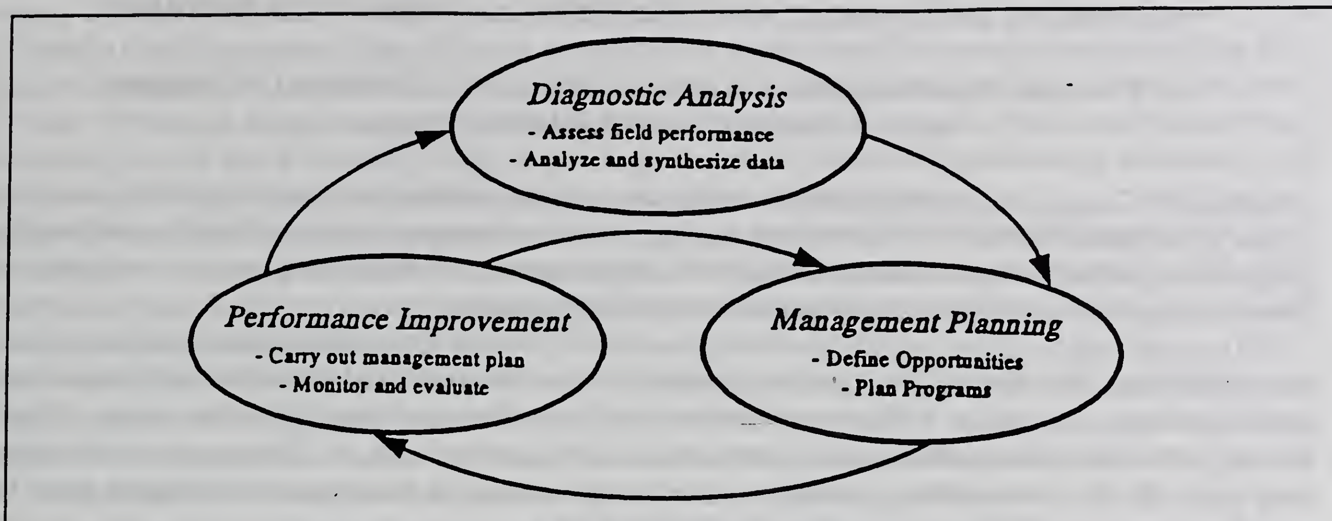
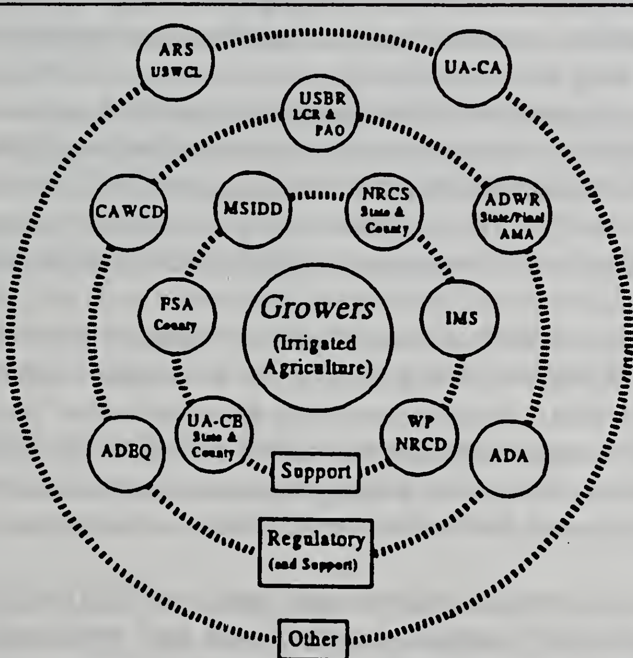


Figure 1. The three phases of the Management Improvement Program feed into one another. Diagnostic analysis yields an interdisciplinary understanding of the performance of irrigated agriculture in the area. Management Planning results in a shared understanding of the performance among growers and participating organizations as well as identification of opportunities for improvement and jointly developed plans for managerial and technological changes to address those opportunities. Performance Improvement results in implementation of the plans and establishment of long-term, self-supporting mechanisms to sustain the effort after the formal end of the MIP.



ADA - Arizona Department of Agriculture
ADEQ - Arizona Department of Environmental Quality
ADWR - Arizona Department of Water Resources
AMA - Active Management Area
ARS - Agricultural Research Service, U. S. Water Conservation Laboratory
CAWCD - Central Arizona Water Conservation District
FSA - Farm Service Agency
IMS - Irrigation Management Service
MSIDD - Maricopa-Stanfield Irrigation & Drainage District
NRCS - Natural Resource Conservation Service
UA-CA - University of Arizona College of Agriculture
UA-CE - University of Arizona Cooperative Extension
USBR - U. S. Bureau of Reclamation
LCR - Lower Colorado Region
PAO - Phoenix Area Office
WPNRCD - West Pinal Natural Resource Conservation District

Figure 2. Schematic representation of entities involved in irrigated agriculture in the MSIDD-Area. Entities were included as participants because of their potential to impact irrigated agriculture in the area. Improved profitability and sustainability of irrigated agriculture (along with improved natural resource management) were the goals of the Demonstration MIP; therefore, growers, the main focus of the program, are shown appropriately in the center. Moving outward from the growers, the first circle connects organizations or entities directly supporting agriculture in the MSIDD area; the second connects organizations with primarily regulatory missions although they may also have some support functions; and the furthest circle includes the two research and/or educational organizations involved.

WATER-USE ASSESSMENT FOR THE IMPERIAL IRRIGATION DISTRICT

A. J. Clemmens, Supervisory Research Hydraulic Engineer; B. T. Wahlin, Civil Engineer;
and J. A. Replogle, Research Hydraulic Engineer

PROBLEM: Changes in cropping patterns, weather, insects, crop markets, etc., can all impact the water use within an irrigation district. Understanding the nature of the changing demands for water and making judgments regarding its appropriateness requires thorough analysis of the farming systems; including the physical irrigation systems and crop irrigation management practices.

The Imperial Irrigation District (IID) is at the tail end of the Colorado River, where unconsumed water flows to the Salton Sea. IID has been under political pressure to reduce diversions and water flow to the Sea through improved irrigation practices. While some water conservation efforts have taken place, the volume of water flowing to the Sea is still significant (on the order of one million acre feet per year). The purpose of this project is to assist the district in defining current water use with existing information, in developing plans for additional data collection, and in identifying opportunities for water conservation.

APPROACH: A Water Study Team was formed to evaluate the water balance within IID, in response to a recent U.S. Bureau of Reclamation (USBR) report that was critical of their water diversions. The team is comprised of Charles Burt and Ken Solomon, Cal Poly; Rick Allen, Utah State University; Ed Craddock, California Dept. of Water Resources; Bert Clemmens, USWCL; and Tim O'Halloran, IID. A water-budget approach will be used to determine the gross annual consumption of water from the Imperial Valley. A weather-based approach will be used to partition this total consumptive use into its various components.

The USWCL is primarily responsible for determining water consumption from the water-budget approach. This method relies on accurate measurement of inflow to and outflow from the Imperial Valley. This approach should work well for this valley since inflow and outflow are predominately on the surface and measurable (i.e., there is very little subsurface flow because of the deep, heavy clay soils).

Five different flow measurement sites were examined in detail during this project: the All American Canal at Pilot Knob, the Alamo and New Rivers at their outlets to the Salton Sea, the New River at the Mexican border, and the flow into the Coachella Canal. The flows in the All American Canal at Pilot Knob and at the New River at the Mexican border are both inflows into IID. The other three sites are considered outflows. All of the sites use current metering to measure the flow except for the entrance to the Coachella Canal, which uses a 50-foot Parshall flume.

To estimate the bias and accuracy at each of these sites, IID's method of current metering was examined to see if they followed the guidelines set by the U.S. Geological Service (USGS) and to evaluate whether those guidelines were appropriate for these sites. Full profiles (10 points) were taken for a few vertical lines at the outlets of the Alamo and New Rivers. This was done to verify that the 0.2/0.8 method of estimating the average velocity in a vertical is viable for these rivers. Old current metering data were also examined for the four current metering sites. The district's calibration of the 50-foot Parshall flume at the entrance to the Coachella Canal was also evaluated.

Other surface and subsurface inflows to and outflows from the district were estimated based on data from IID staff, from published geologic and hydrologic reports, and from weather station data. This information was then used to determine total water consumption (primarily evapotranspiration, ET) within the valley, as the remainder in the water budget. Estimates of irrigation water consumption other than for crop production (e.g., canal evaporation, phreatophyte ET, etc.) were then subtracted from the total to determine consumption of irrigation water for crop production. Three other water budgets were used to provide a better picture of the various water uses: inflow and outflow from the district's canal system, aggregate inflow and outflow from farm irrigation systems, and aggregate inflow and outflow from the open-drain river system.

FINDINGS: An analysis of the flow measurement sites for IID has been completed. Table 1 shows the various sites and the confidence intervals (CI) for an individual flow rate from current metering, an individual flow rate estimated from a stage measurement, and the measured annual volume. There are significant differences in the

nature of these sites, as reflected in relative differences in the values of these confidence intervals. The Coachella Canal flume shows little difference in accuracy for an individual flow versus accumulated flow since the error is primarily in the calibration, which doesn't change. For the All American Canal at Pilot Knob, there is little difference in the accuracy of an individual current metering compared to a stage based measurement, indicating that the site is extremely stable. It also suggests that an unbiased stage-discharge relationship can be developed that need not be adjusted based on current meter measurements.

For the New River at the Mexican border, the site is not as good as Pilot Knob, as evidenced by the higher current meter and stage-based-discharge uncertainty. However, because this site has very stable flow conditions, random current meter errors don't significantly influence the error in annual volume, even though current meterings are infrequent.

In contrast, the Alamo River at the outlet to the Salton Sea has flow conditions that vary significantly over the year. In the analysis of confidence intervals, this is reflected as a process uncertainty- -that is, between individual current meterings we are uncertain how much the head-discharge relationship will change. Thus the CI for discharge based on stage is much, much higher than the CI of the current metering. On the other hand, The New River at the outlet has less accuracy for its individual current metering (7.2% compared to 6.2% for the Alamo River), due to its very unusual cross section. However, it is relatively more stable than the Alamo River site and thus has less process variability. For these sites, the process variability has more influence on the overall estimate of the accuracy of annual volume than for AAC or New River at the Mexican border.

These measurement sites account for a majority of the volumes entering and leaving the valley, except for evapotranspiration. Other minor inflows to and outflows from the valley are estimated and consumption within the valley (essentially evapotranspiration) is the remainder in a water balance. The variance of this remainder is the sum of the variances of the components. The variance (V) can be computed from the annual volume (m) and its confidence interval (CI), where $CI = 2\ s/m$, $V = s^2$, and s is the standard deviation. The water balance components for 1990 are shown in Table 2, along with CI and V. These are sorted in order of decreasing contribution to the overall variance (i.e., greatest contribution at the top of the list). Those components with the highest variance have inaccuracies that have the most influence on the accuracy of the remainder. This consumption must be further partitioned into consumption on agricultural and non-agricultural land and into consumption of irrigation water and consumption of other inflows (e.g., rainfall, New River inflows, etc.). Further details will be provided in a report prepared for IID.

INTERPRETATION: Methods are now available for detailed assessment of the accuracy of current meter stations, as well as measurement structures. This can aid in the siting of these stations, on analysis of data, and on recommendations for site improvement or remediation. Total evapotranspiration for the Imperial Valley appears to be reasonably well estimated with the water balance.

FUTURE PLANS: The water balance for the years 1987 to 1996 need to be finalized and compared to weather and crop-based estimates. Additional work needs to be done to determine whether a nonstandard transition between a Parshall flume and the main channel can cause a shift in the calibration.

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Table 1. Confidence intervals for IID measurement sites.

Site	CI for individual current metering	CI for individual discharge based on measured stage	CI for annual volume
All American Canal at Pilot Knob	± 5.6%	± 5.6%	±1.9%
Coachella Canal Flume	Not applicable	± 3.0%	±2.2%
Alamo River at Mexican border	Site not studied	Site not studied	Volume insignificant
New River at Mexican border	± 8.4%	± 8.7%	± 2.0%
Alamo River at Salton Sea outlet	± 6.2%	± 24.4%	± 2.6%
New River at Salton Sea outlet	± 7.2%	± 14.7%	± 2.1%

Table 2. Water balance components and their accuracy for the Imperial Valley, 1990.

	Volume	**Accuracy CI**	**Variance**
	(1,000 ac-ft)	% reading	(1,000 ac-ft)^2
Delivery to AAC at Pilot Knob	3420	1.9	1055
Seepage (PK to EHL)	-94	30%	200
ET - drains, rivers, phreatophytes	-89	27%	147
Rainfall Volume	91	22%	105
Subsurface inflows	20	100%	100
Change in Storage	0	--	100
Direct outflow to Sea	-91	20%	83
Sum of Alamo & New River outflow to Sea	-1049	misc.	74
Sum of all others	-325	misc.	75
Total Water consumption on Agricultural Land	1882	4.7	1939

IRRIGATION CANAL AUTOMATION

A.J. Clemmens, Supervisory Research Hydraulic Engineer; R.J. Strand, Engineering Technician; and E. Bautista, Agricultural Engineer

PROBLEM: Modern, high-efficiency irrigation systems require a sufficiently flexible and stable water supply. Open-channel water delivery distribution networks are typically not capable of this high level of service. Stable flows can be achieved when little flexibility is allowed, since canal operators can force canals flows to be relatively steady. Allowing more flexibility increases the amount of unsteady flow and leads to more flow fluctuations to users.

Most canal systems operate with manual upstream control. The disadvantage of this system is that all flow errors end up at the tail end of the system. In large canals, supervisory control systems are used to adjust volumes in intermediate pools to keep differences between inflow and outflow more evenly distributed in the system or simply stored until a balance is achieved. Smaller canals with insufficient storage need more precise downstream control methods than are currently available. Development of improved canal control methods requires convenient simulation of unsteady flow by computer. Many computer models of unsteady canal flow have been built in the last twenty years, some very complex and expensive, designed to model very complicated systems. Only recently have these programs been geared toward canal automation so that simulation of control algorithms could be efficiently made.

The objective of this research is to develop tools to promote the adoption of improved canal operating methods. This includes development and testing of canal control algorithms, development of necessary sensors and hardware, development of centralized and local control protocol, refinement of simulation models needed for testing these methods, and field testing of algorithms, hardware, and control protocol.

APPROACH: A Cooperative Research and Development Agreement between ARS and AUTOMATA, Inc., was established for the purpose of developing off-the-shelf hardware and software for canal automation. We will work closely with AUTOMATA in the application and testing of this new hardware and software. Cooperation with the Bureau of Reclamation's Water Resources Laboratory was also established to support this research. Theoretical analysis and computer simulation modeling will be conducted to determine the performance and functionality of various control algorithms and schemes. These methods will be field tested as much as possible.

Control engineering will be used to develop control algorithms for one or more canals within the Maricopa-Stanfield Irrigation and Drainage District (MSIDD). These control algorithms will be written into control software for the central computer. Where possible, as much logic as practical will be written into the Remote Terminal Unit (RTU) software so that control can be more precise. New gate position sensors will be developed and tested to provide finer resolution of gate movement, while still providing absolute position. Several control algorithms will be tested to compare the various advantages and disadvantages of these controllers and tuning methods. Gate-stroking will be used to determine the kind of feedforward logic that needs to be included to route known flow changes through the canal, represented as a series of canal pools with gates.

FINDINGS: A feedforward control algorithm anticipatory open-loop control has been developed and programmed for implementation on SRP's Arizona Canal. This program should also be usable for the general canal control scheme. The feedback control scheme appears to be less critical to performance than thought earlier. While it is an essential component, it doesn't have to be overly aggressive or sophisticated. Integrating this scheme into existing operating methods appears to be more important.

Attempts to implement feedback and feedforward control algorithms on various canals have underscored the need to control both water levels and flow rates. While this seems easy in concept, it is not always straightforward to implement. Many of the simple feedback control algorithms control only water levels, while gate-stroking (feedforward with anticipation) algorithms control only flow rates. In reality, these simple methods control one (flow or level) with the assumption that if that function is done properly control of the

other will be "automatic," for example as the result of structure properties. There are a number of scenarios where these two simple approaches are not adequate.

We use a hierarchical (or master-slave) control scheme to control both water levels and check-gate flow rates. If the offtake flows are set correctly, level control at each pool will result in flow control for the canal as a whole. Suppose that an offtake flow from one pool is suddenly increased. The flow controller at the check gate (slave) keeps this disturbance from traveling downstream and affecting other pools and downstream deliveries, in effect decoupling the downstream pools from this disturbance. This is only possible if feedback brings the needed flow change from some upstream supply source. However, if you rely on water level changes in each pool to provide all of the feedback, then the water levels in all upstream pools must change in order to send the feedback signal upstream to the source, since all upstream gate flows must change by the amount of the offtake change. In an attempt to limit this effect on all upstream pools, the flow change requested from the pool experiencing the change in offtake flow is sent to each upstream gate. In essence, this is an upstream decoupler in that it tries to reduce the effect of flow changes in one pool on the water levels of upstream pools.

A change in flow at the upstream end of a canal pool results in a wave that travels down the canal at some velocity and arrives at the downstream end some time later (i.e., the pool has a time delay). When pools have response time delays, this upstream decoupling can never be perfect since, during the delay, the pool levels change and the feedback controller will duplicate the needed flow change. This can result in disturbance amplification in the upstream direction. Thus, only some fraction of the requested flow change should be passed upstream. This can become a difficult controller design problem and suggests the need for a separate disturbance controller. A global, optimal controller; i.e., a controller that derives control signals for all pools simultaneously, incorporates this type of decoupling action.

Regarding the application of AUTOMATA hardware to the WM canal at the Maricopa-Stanfield Irrigation and Drainage District, the new RTUs, gate position sensors, and base station have been installed and are communicating with one another. Some programming has been done on the RTU gate control software, but it is not yet complete. A few water-level sensors still need to be installed.

The simulation software program CANALCAD now allows the control subroutines with global access to simulation variables and thus the ability to program centralized control schemes. This will be utilized to test various canal algorithms for application on the WM canal.

It seems useful to link our control algorithms to commercial SCADA packages. Several of the leading packages allow developers to program control functions into their systems. However, some of them are limited in the programming languages that can be used and, thus, are limited in their functionality.

INTERPRETATION: The feasibility of a plug-and-play type canal automation system looks promising. Ensuring proper functioning of the system for a given canal will still require some engineering analysis to ensure that it performs adequately.

FUTURE PLANS: Programming for the RTU and base-station software will be completed over the next year. Field testing will begin with a simple controller. More complex controllers will be tested as they are developed. Work will continue on the development of feedback and disturbance controllers that perform better under unusual circumstances. A lateral canal with properties somewhat different from the WM canal will be selected for future analysis and testing of control algorithms.

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CANAL AUTOMATION PILOT PROJECT FOR SRP'S ARIZONA CANAL

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PROBLEM: The Salt River Project (SRP) has a long history of being progressive in the management of its water distribution system. SRP's Roosevelt dam was the first to be built under the Reclamation Act of 1902. The district also took control of the distribution network from the Bureau of Reclamation in 1917 to improve service to their water users. SRP developed its own supervisory control system in the mid 1960's, covering its entire network of main canals. In the 1980's, SRP embarked on an intensive water measurement program to reduce unaccounted for water losses. With the conversion from agriculture to large urban water users, water quality is becoming a more important issue, and supervisory control operators are spending more and more of their time on such issues (e.g., maintaining acceptable water quality at the inlet to city water treatment plants). In the early 1990's, SRP constructed a new operations center with a state-of-the-art SCADA (Supervisory Control And Data Acquisition) system.

Studies in the 1970's by Zimbelman suggested that SRP's main canals could be operated with automatic downstream feedback control. Significant advances have been made in methods for canal automation with feedback control. The objective of this project is to determine the feasibility of implementing canal automation within SRP's distribution network.

APPROACH: A pilot project was initiated with SRP to test the potential of an automatic controller on the first five pools of the Arizona canal. The control system combines open-loop routing of known flow changes (feedforward), a closed-loop (feedback) controller to handle disturbances or errors in flow settings, and flow control at the check structures. In the initial stage of this project, we will study the feasibility of this control scheme through unsteady-flow simulation. If this proves successful, we will explore the possibility of testing the scheme in real time on the canal.

Unsteady flow will be simulated with an existing software package that SRP purchased, MIKE-11. The model was calibrated by the Danish Hydraulics Institute (DHI). SRP will assist us in collecting data on the response of the canal. This data will be used to test the MIKE-11 model calibration under unsteady flow conditions that are typical of control situations. DHI will add a user interface to the MIKE-11 software to accommodate our control logic. Unsteady-flow simulations with MIKE-11 will be made to determine the response characteristics of the pools between check gates. Based on these results, the closed-loop controller will be determined from analysis with the control system software, MATLAB. Next we will program the control logic into the user interface to MIKE-11 so that it can be tested with Mike-11.

SRP will develop a series of control scenarios that represent typical operating conditions faced by the supervisory control operators. These control situations will be used to test the various features of the control system through unsteady-flow simulation with MIKE-11.

FINDINGS: The interface to Mike-11 was successfully completed. The control logic was coded as Mike-11 subroutines to provide feedforward, feedback and flow control functions (i.e., to actually change gate positions and inflow or demand changes) from Mike-11 generated water levels. This model was also used to determine the response of canal pools to upstream flow changes. This canal response information was then used to develop the feedback control model and its coefficients.

SRP's test scenarios were used to examine the performance of the various controllers developed. Several of the tests represented typical daily variations in demand. Some of these were examined with feedback only, feedforward only, or combined feedback-feedforward. The flow control function was used in all cases, either with perfect information (perfect flow control) or with difference in the gate head-discharge relationship between the unsteady simulation model and the flow control function. A number of other tests were more extreme, with large flow changes, failed gates, etc.

In general, small flow changes (e.g., $< 1\ m^3/s$) could be handled adequately with feedback control only (no feedforward). With feedforward control alone, the water levels drifted away from the set points over time.

Large flow changes (e.g., > 4 m^3/s) required feedforward control with anticipation of the flow change ahead of time. Otherwise, the waterlevels deviated substantially from the setpoint for long periods of time (i.e., hours).

Figure 1 shows the results of feedback control only for a small change in flow (2.5% of the initial flow at the headgates) at the downstream end of the 30 km long canal. The system is easily able to handle this flow change. Figure 2 shows the results of a combined feedback-feedforward (with anticipation) controller for a large flow change (about 25% of the initial flow). When the change is anticipated, the controller is able to keep the water level deviations within the allowable range (±0.25 ft). More details are provided in the report on Phase I of this project.

Tests were run to determine whether system identification techniques could be used to estimate canal response from field measurements, as opposed to the use of simulation models, which of course also need to be calibrated and validated. For these tests, a varying inflow hydrograph was established at the head of a canal pool. (Tests were run one pool at a time). An example of the inflow and outflow response is given in figure 3. Then the water level response was used to identify the relationship (model) between upstream pool inflow and pool downstream water level. Research is ongoing to determine whether this response model can be used for controller design.

At the start of the project, baseline information was not available from which to judge whether canal automation could improve operations. We collected data from a three day period and attempted to compare what the controller would have done relative to how well the operators performed. This comparison is shown in figure 4. It appears that the automatic control system can do as well or better at maintaining constant water levels. Further analysis is being performed to determine whether or not the conditions during these three days are representative.

INTERPRETATION: Based on the analysis to date, it appears that canal automation (remote computer control) has some real potential for improving canal operations over supervisory (manual remote) control. The magnitude of flow changes that can be allowed is still limited by the canal's hydraulic properties. Automation itself cannot fully overcome these limitations.

FUTURE PLANS: SRP has funded the second phase of this project in which we will program the automatic control system into their SCADA computer. Once this has been completed, the system will be tested on-line. There are three main components. The feedforward controller will be linked to SRP's existing water ordering and billing database. Water orders entered into this database will be used to schedule check gate flow changes upstream to Grainte Reef Diversion so that the order can be satisfied on time. The program will tie into SRP's existing water ordering and billing database. The feedback controller will take water levels from the SCADA database and determine needed changes in check gate flows (i.e., it changes the inflow to each pool to maintain the preset forebay water levels). The feedback and feedforward flow changes are sent to the SCADA computer's autocontrol function for each check gate. The autocontrol function will adjust check gate positions to maintain the target flow rate.

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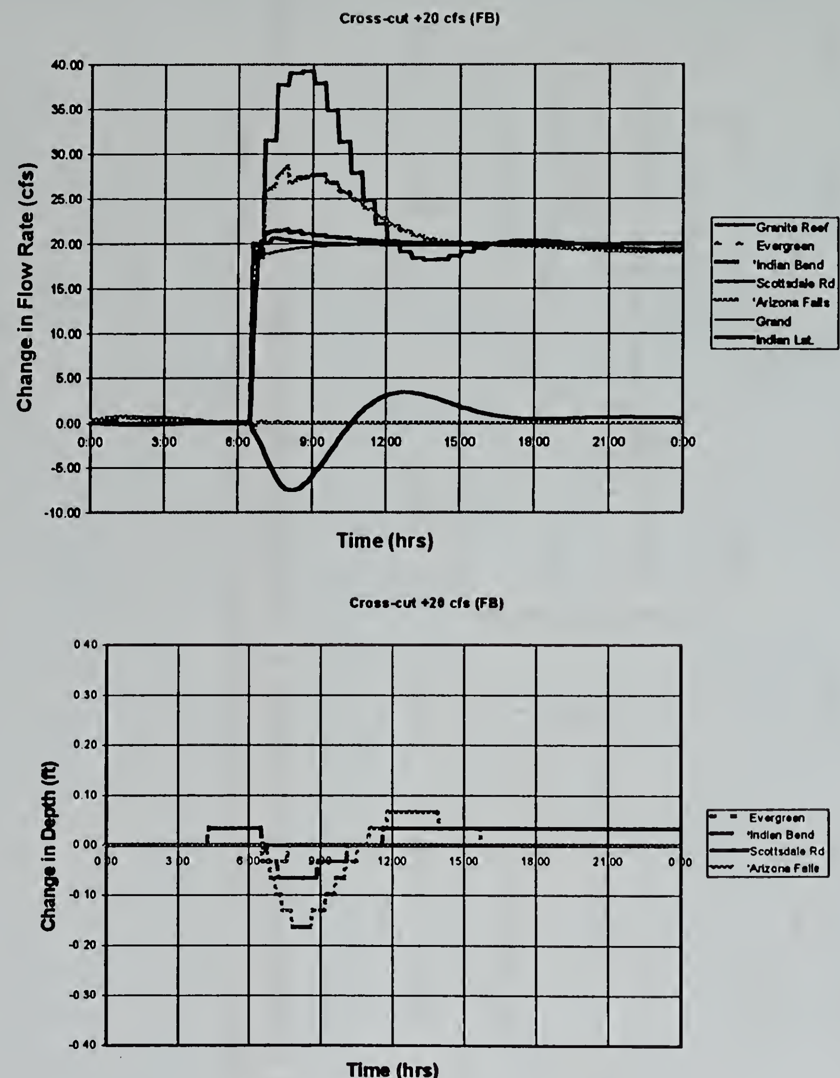

Figure 1. Water level and flow variations for test 1: feedback control.

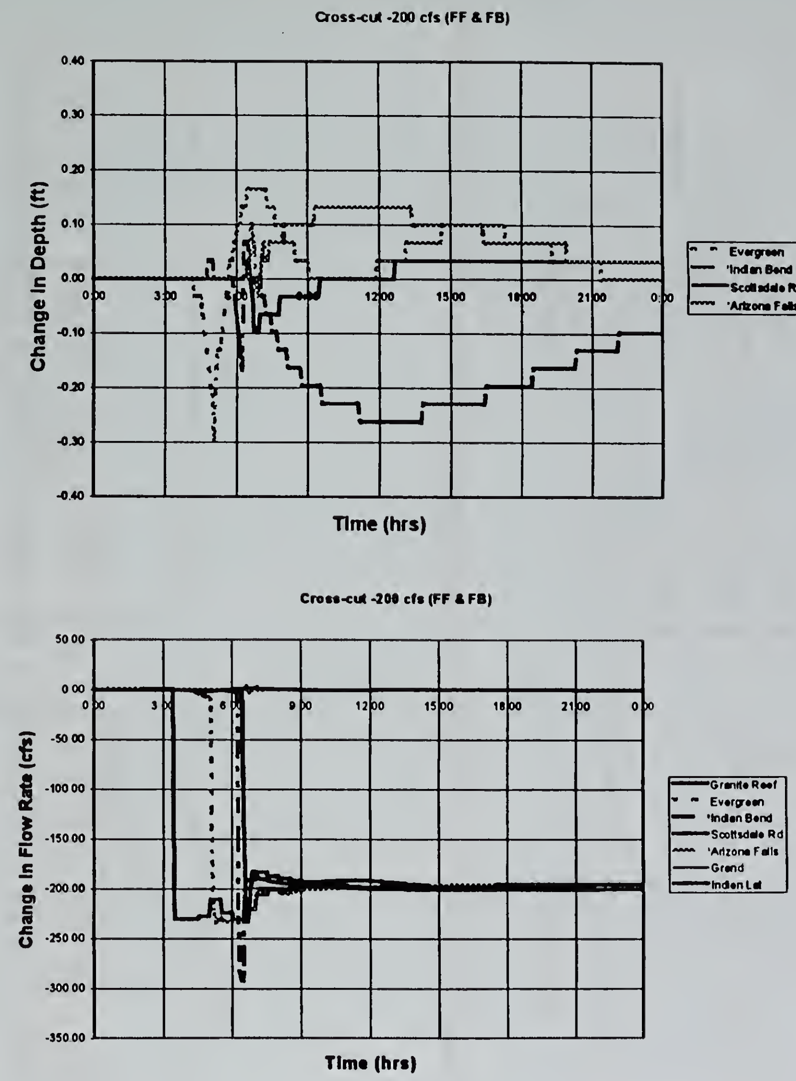

Figure 2. Water level and flow variations for test 5: feedback and feedforward control.

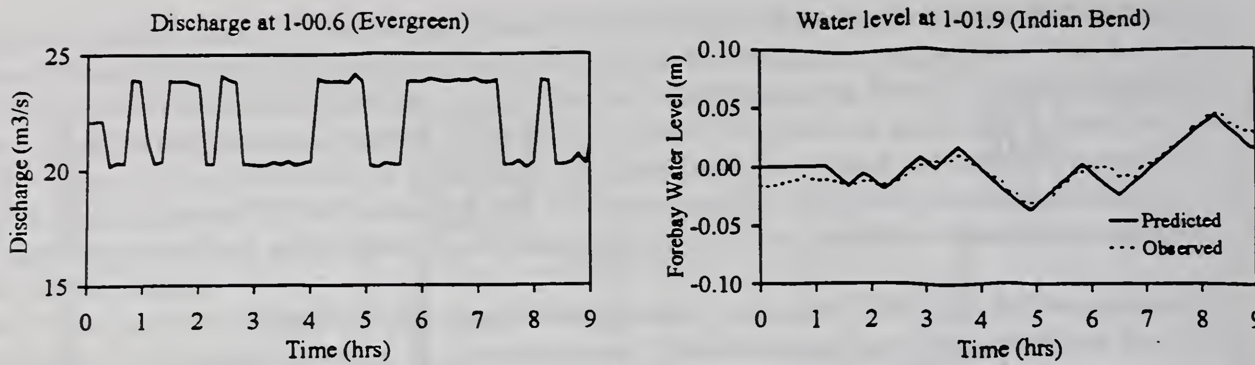

Figure 3. Applied discharge at the 1-00.6 check gate and resulting water level variation at the 1-01.9 forebay.

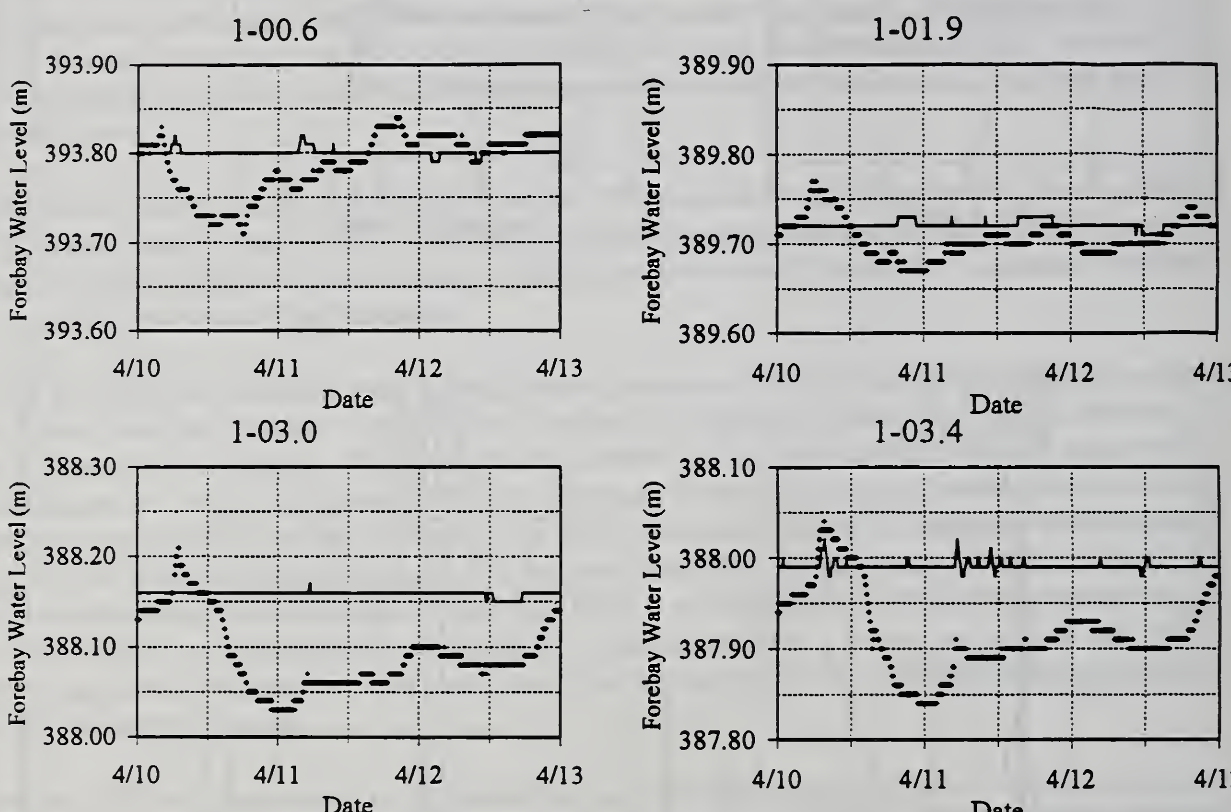

Figure 4. Observed (symbols) water level variations in four manually-controlled Upper Arizona Canal forebays (April 10-12, 1997) and predicted (line) level variations with automatic control.

PLANT GROWTH AND WATER USE AS AFFECTED BY ELEVATED CO_2 AND OTHER ENVIRONMENTAL VARIABLES

PROGRESS AND PLANS FOR THE FREE-AIR CO_2 ENRICHMENT (FACE) PROJECT

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PROBLEM: The CO_2 concentration of the atmosphere is increasing and is expected to double sometime during the next century. Climate modelers have predicted that the increase in CO_2 will cause the Earth to warm and precipitation patterns to be altered. This project seeks to determine the effects of such an increase in CO_2 and any concomitant climate change on the future productivity, physiology, and water use of crops.

APPROACH: Numerous CO_2 enrichment studies in greenhouses and growth chambers have suggested that growth of most plants should increase about 30% on the average with a projected doubling of the atmospheric CO_2 concentration. However, the applicability of such work to the growth of plants outdoors under less ideal conditions has been seriously questioned. The only approach which can produce an environment as representative of future fields as possible today is the free-air CO_2 enrichment (FACE) approach.

Therefore, from December 1993 through May 1994 two FACE experiments were conducted on wheat at ample and limiting levels of water supply, with about 50 scientists from 25 different research organizations in eight countries participating. About 20 papers have been published or are in press from these experiments, and several more are being prepared.

However, one of the greatest uncertainties in determining the impact of global change on agricultural productivity, as well as natural ecosystems, is the response of plants to elevated CO_2 when levels of soil nitrogen are low. Therefore, we conducted an initial FACE Wheat experiment at ample and limiting supplies of soil nitrogen from December 1995 through May 1996, and a second replicate experiment was conducted this past year from December 1996 through May 1997. Funded by the Department of Energy through a grant to the University of Arizona, U.S. Water Conservation Laboratory personnel were major collaborators on the project and provided management support. A new feature of the 1995-6 and 1996-7 experiments was that blowers were added to the control plots to make them more like the FACE plots.

As in the previous experiments, measurements included: leaf area, plant height, above-ground biomass plus roots that remained when the plants were pulled, apical and morphological development, canopy temperature, reflectance, chlorophyll, light use efficiency, energy balance, evapotranspiration, soil and plant elemental analyses, soil water content, photosynthesis, respiration, stomatal conductance, antioxidants, stomatal density, decomposition, grain quality, video observations of roots from minirhizotron tubes, soil CO_2 and N_2O fluxes, and changes in soil C storage from soil and plant C isotopes. In addition, soil cores and leaf samples were obtained and were stored frozen for later analyses of root biomass and soil nitrogen, photosynthetic proteins, and carbohydrates. Thanks to a grant from a NSF/DOE/NASA/USDA program (TECO) and ARS Temporary Global Change Funds, personnel to do these analyses have been hired, and the analyses are underway.

All of the data will be assembled in a standard format for validation of wheat growth models. Several collaborating wheat growth modelers plan to utilize the data.

FINDINGS: Analyses of the data from both the 1995-6 and 1996-7 FACE Wheat Experiments are underway, as reported by Pinter et al., Wall et al., Brooks et al., Hunsaker et al., Adam et al, and Kimball et al. in this volume. Briefly, the preliminary results indicate that, under the high nitrogen treatment, wheat grain yields were increased about 15% by FACE at 200 μmol/mol above ambient, which is somewhat more than the 10% increase obtained in the two prior experiments. At low nitrogen, yields increased about 12%. The low nitrogen treatment reduced yields about 20% at both levels of CO_2. Water use was unchanged, as indicated by water balance measurements.

INTERPRETATION: These data plus those from our prior FACE wheat experiments suggest that with ample water wheat production is likely to increase 10-15% by an increase in atmospheric CO_2 levels to 200 µmol/mol above current levels (about 370 µmol/mol). Moreover, in contrast to many chamber studies, our results suggest that the yield increases will occur even at the low levels of soil nitrogen characteristic of the agriculture in developing countries and most natural ecosystems. Irrigation requirements may be unchanged or slightly reduced for future wheat production, provided climate changes are minimal.

FUTURE PLANS: First, analyses and reporting of the results from the 1995-7 FACE Wheat experiments will be completed. Then, as part of the NSF/DOE/NASA/USDA/EPA Joint Program on Interagency Terrestrial Ecology and Global Change ("TECO III"), the FACE Project will continue on sorghum in two replicate experiments in the 1998 and 1999 summer growing seasons. The interaction of elevated CO_2 and soil water supply on the growth, physiology, and water relations of this important world crop will be studied.

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ACCLIMATION OF THE PHOTOSYNTHETIC APPARATUS OF SPRING WHEAT GROWN UNDER FREE-AIR CO_2 ENRICHMENT (FACE) AND TWO SOIL NITROGEN REGIMES

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PROBLEM: Atmospheric CO_2 concentration (C_a) is rising and is predicted to almost double over the next century. In addition to the impact of elevated CO_2 on the transport processes of CO_2 and H_2O due to the CO_2-based regulation of stomatal conductance (g_s), many CO_2 enrichment studies have shown that any increase in net assimilation rate (A) has been short-lived. Consequently, the initial increase in A due to elevated CO_2 declined to the pre-exposure levels within a few days. This suggested that acclimation or *down-regulation* of the photosynthetic apparatus occurred under long-term exposure of plants to elevated CO_2. Comparative studies have shown that *down-regulation* varies with species (domesticated, wild types), environmental constraints such as limited soil nitrogen which alters the allocation of resources amongst the photosynthetic apparatus (Webber et al., 1994), and with cultural practices such as rooting media--small pots (≤ 5 L) which restrict sinks such as roots, whereas large pots (≥ 20 L) and open field studies do not (Sage, 1994). Hence, we need to test the hypotheses that a C_3 cool season annual grass such as wheat grown in an open field under elevated CO_2 and limited nitrogen supply will experience acclimatory changes within the photosynthetic apparatus (Hypothesis 1), but that this acclimation will be confined to changes in biochemical processes within the calvin cycle rather than due to stomatal effects (Hypothesis 2).

APPROACH: A field study on a hard red spring wheat (*Triticum aestivum* L. cv. Yecora Rojo) crop was conducted in an open field at The University of Arizona, Maricopa Agricultural Research Center, located 50 km south of Phoenix, Arizona (33.1 °N, 112.0 °W). Wheat seeds were sown into flat beds in east-west rows parallel to the drip tape that was spaced 0.25 m apart on December 14-15, 1995, and December 15, 1996. Seeding rates were 109 kg ha^{-1} (~236 seeds m^{-2}; planting density of 189 plants m^{-2}) during 1995 and 111 kg ha^{-1} (~252 seeds m^{-2}; planting density of 194 plants m^{-2}) during 1996 (50% emergence occurred on January 1, 1996, and the crop was harvested on May 29-30, 1996; 50% emergence occurred on December 30, 1996, and the crop was harvested on May 28-29, 1997). Following sowing, a Free-Air CO_2 Enrichment (FACE) apparatus was erected on site to enrich the CO_2 concentration by approximately 200 µmol mol^{-1} (FACE: F) (main plot) above ambient air (ca. 370 µmol mol^{-1}) (Control: C) over the wheat crop. Enrichment began within a few days of 50% emergence (January 1, 1996; January 3, 1997) for 24 hrs until physiological maturity (May 15, 1996; May 12, 1997). A sub-surface drip tape irrigation system supplied a full irrigation of 100% evaporative demand with seasonal totals of 621 and 548 mm during 1996 and 1997, respectively. Nitrogen (N) fertilizer (NH_4NO_3) was delivered during the mid-tillering, anthesis, and early grain fill irrigations for a High (350 kg $season^{-1}$ ha^{-1}: H) and Low (70 and 15 kg $season^{-1}$ ha^{-1} for 1996 and 1997, respectively: L) treatment to each half of the main CO_2 treatments (split-plot)–*strip-split-plot* experimental design. Treatments, therefore, consisted of FACE-Low (FL), FACE-High (FH), Control-Low (CL), and Control-High (CH). Leaf gas exchange rates (A, g_s) were measured with a portable closed-exchange (transient) system with a 250 cm^3 transparent assimilation chamber on the central portion of five fully expanded (ligule emerged) upper-canopy sunlit leaves (three replications) from dawn to dusk at the 5-leaf, tillering, stem-elongation/boot, anthesis, grain filling and dough/milk-ripe growth stages which corresponded with days after planting (DAP) 062, 083, 103, 116, 130 and 144 during 1996, and for all growth stages except grain filling which corresponded with DAP 051, 079, 095, 115 and 137 during 1997, respectively. Daily accumulation of carbon was obtained by integrating the dawn to dusk values of A.

FINDINGS: Dawn to dusk trends in A for all growth stages measured during both seasons are depicted in Figure 1. The midday maximum values of A followed a consistent trend regardless of growth stage: FH were

the highest; CL were the lowest; FL and CH were intermediate in their response. Over the two years the seasonal main effect CO_2 mean for daily leaf carbon accumulation was 31% greater in F compared with C, whereas the main N effect mean was 20% greater in H compared with L. Over two years elevated CO_2 stimulated daily accumulation of carbon by 30% under H, but it was only 23% greater under L. Hence, a 7% reduction in the CO_2 stimulation effect was observed in L compared with H. Significant two-way interactions (*CO_2xN*) were observed during anthesis (*p=0.14*) (Fig. 1g) and boot (*p=0.03*) (Fig. 1f) during 1996 and 1997, respectively. These interactions occurred because of an 11% (anthesis, 1996) and 21% (boot, 1997) greater proportionate change in daily total carbon assimilated between H and L under F compared with C (data not shown). The same two-way interaction was observed in the carboxylation efficiency (initial slope of A/Ci curve; C_i, internal CO_2 concentration at the site of carboxylation), and the maximum rate of carboxylation ($V_{c,max}$) (Adam et al., 1997, this volume)-- Hypothesis 1 accepted.

An increase in C_a did reduce g_s (Fig. 2), but for a well-watered wheat crop this decrease was not sufficient enough to affect the C_i/C_a ratio. These data suggest that no acclimation of stomata occurred regardless of CO_2 or N. Hence, the acclimation response observed in A was limited to changes in biochemical processes within the calvin cycle rather than due to stomatal effects--Hypothesis 2 accepted.

INTERPRETATION: For well-watered wheat any reduction in A resulting from a CO_2-induced lowering of g_s was generally offset by an increase in the CO_2 gradient between the atmosphere and substomatal cavity. These compensatory factors, therefore, maintained the midday C_i/C_a ratio at ~0.70. Consequently, any indication of an acclimatory response of the photosynthetic apparatus is based on biochemical rather than transport processes. Significant two-way (*CO_2xN*) interactions did occur under elevated CO_2 and low nitrogen. Furthermore, the magnitude of the difference in the stimulatory effect of CO_2 observed under high compared with low nitrogen was high enough to support the premise that major alterations in the quantity of polypeptides and their activation state within the photosynthetic apparatus occurred. Furthermore, the photosynthetic apparatus is not usually catabolized for translocated of nitrogen out of the leaf during stem-elongation and boot so that the acclimatory response reported herein can not be confounded with senescence effects. Hence, our results support the premise that *down-regulation* of the photosynthetic apparatus occurred due to elevated CO_2 and limited nitrogen supply. Further evidence of this will be derived from biochemical-based assays which will quantify Rubisco-L and Rubisco-S content, Rubisco activation state and number of active sites, and the steady-state levels of mRNA for *RbcS* and rbcL which are presently underway.

FUTURE PLANS: A two-year FACE experiment utilizing sorghum (*Sorghum bicolor* L. Moench) is scheduled for the 1998 and 1999 growing seasons (June-October). The focus of this field study will be to explore the water relations of the sorghum ecosystem under elevated CO_2 and drought.

COOPERATORS: See FACE cooperator listing given by Kimball et al. (1997) in this volume.

REFERENCES: Sage, R.F. 1994. Acclimation of photosynthesis to increasing atmospheric CO_2: The gas exchange perspective. *Photosynthesis Research.* 39: 351-368.

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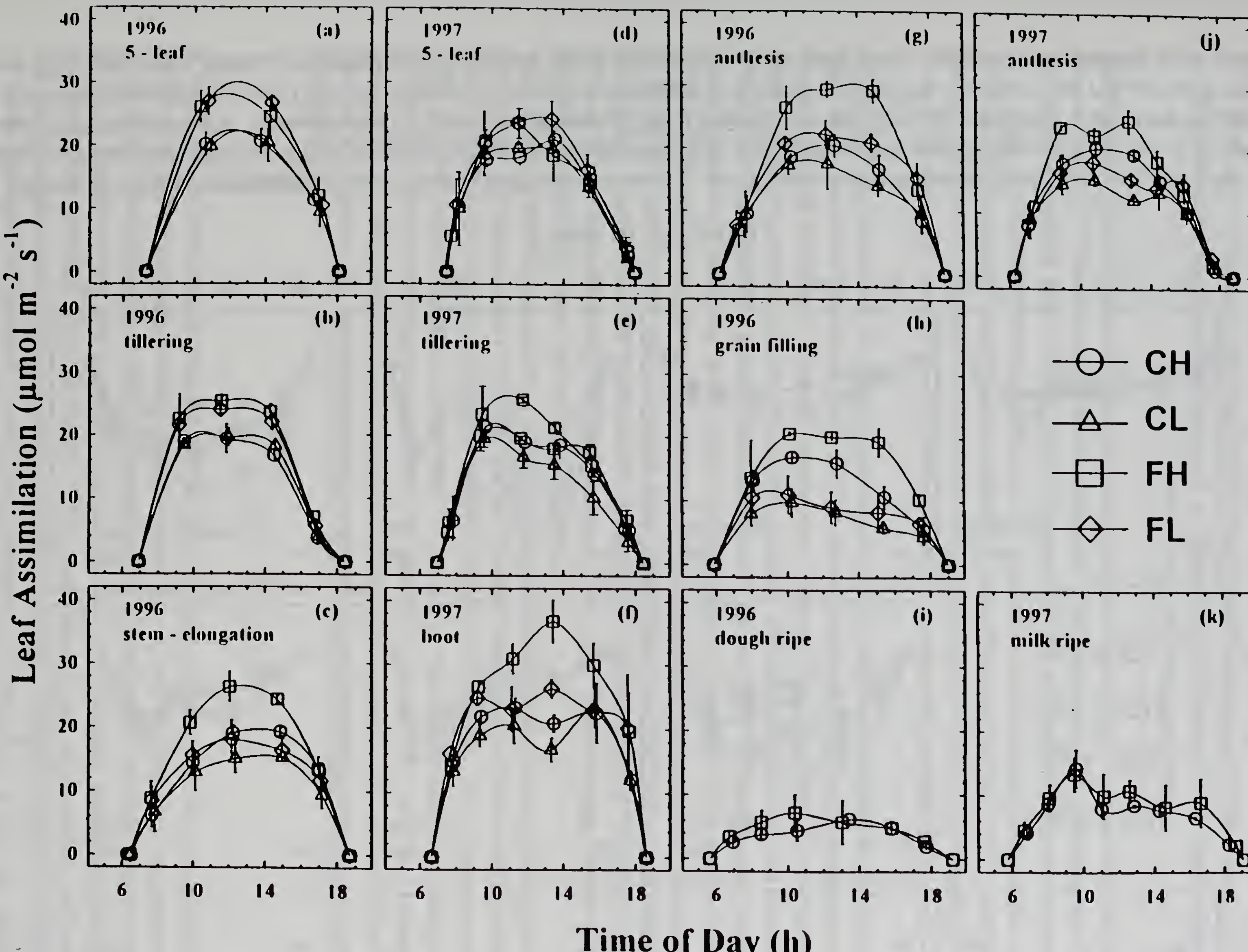

Figure. 1. Dawn to dusk means±standard error wheat (*Triticum aestivum* L. cv. Yecora Rojo) net assimilation rate (A) in fully-expanded sunlit leaves at 5-leaf (a,d), tillering (b,e), stem-elongation (c,f,), anthesis (g,j), grain filling (h), and dough and milk ripe (i,k) growth stages for 1996 and 1997, respectively. Atmospheric CO_2 concentrations of 360 (Control) and 550 (FACE) μmol mol^{-1}, and Low (70 and 15 kg ha^{-1} for 1996 and 1997, respectively) and High (350 kg ha^{-1}) nitrogen correspond to Control-High (CH), Control-Low (CL), FACE-High (FH) and FACE-Low (FL) treatments. Means composed of 5 leaves for three replication. Error bars given represent one standard error from mean.

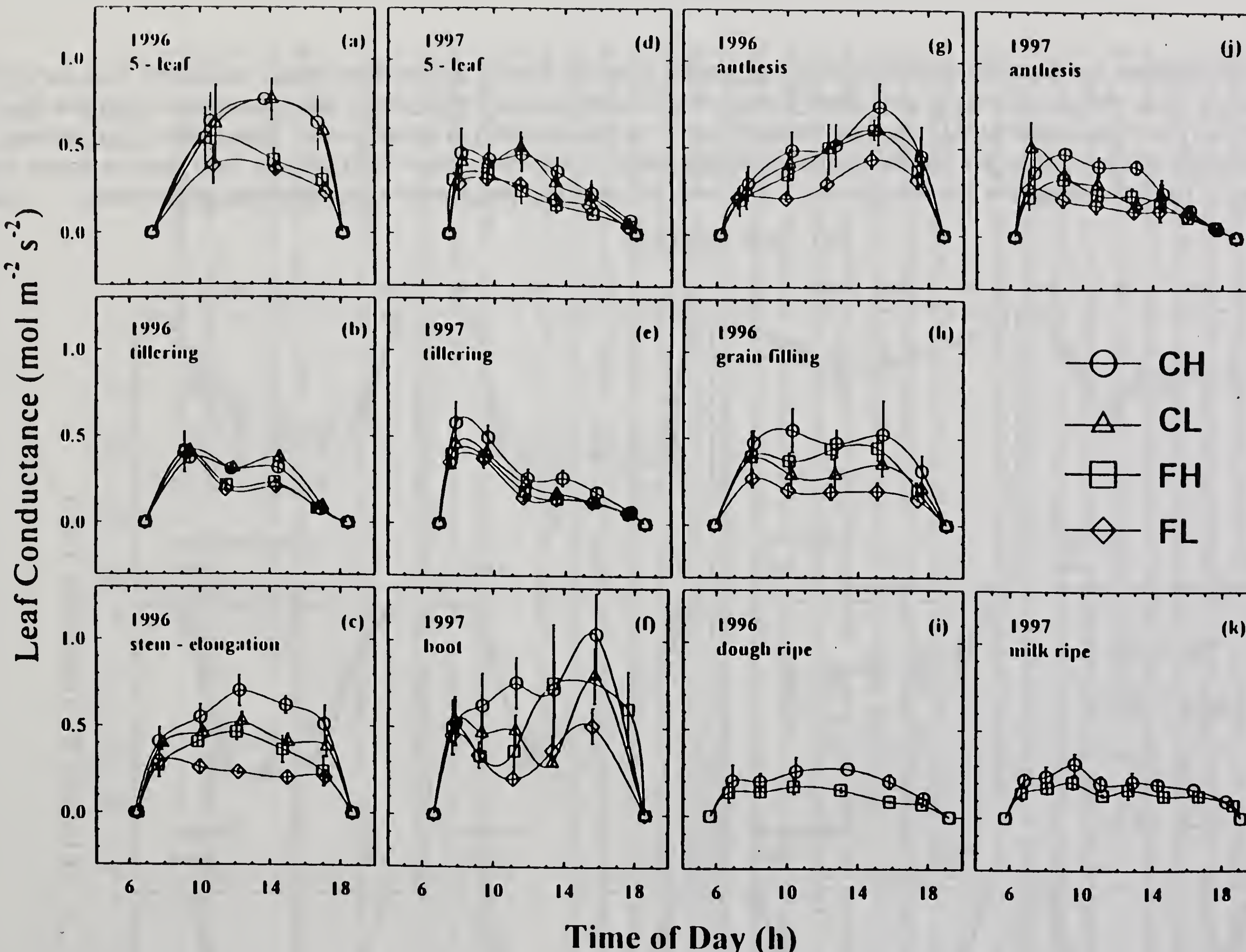

Figure. 2 Dawn to dusk means±standard error wheat (*Triticum aestivum* L. cv. Yecora Rojo) stomatal conductance (g_s) in fully-expanded sunlit leaves at 5-leaf (a,d), tillering (b,e), stem-elongation (c,f,), anthesis (g,j), grain filling (h), and dough and milk ripe (i,k) growth stages for 1996 and 1997, respectively. Atmospheric CO_2 concentrations of 360 (Control) and 550 (FACE) µmol mol^{-1}, and Low (70 and 15 kg ha^{-1} for 1996 and 1997, respectively) and High (350 kg ha^{-1}) nitrogen correspond to Control-High (CH), Control-Low (CL), FACE-High (FH) and FACE-Low (FL) treatments. Means composed of 5 leaves for three replication. Error bars given represent one standard error from mean.

EFFECTS OF FREE-AIR CO_2 ENRICHMENT (FACE) AND SOIL NITROGEN ON THE ENERGY BALANCE AND EVAPOTRANSPIRATION OF WHEAT

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PROBLEM: The CO_2 concentration of the atmosphere is increasing and expected to double sometime during the next century. Climate modelers have predicted that the increase in CO_2 will cause the Earth to warm and precipitation patterns to be altered. Such increases in CO_2 and possible climate change could affect the hydrologic cycle and future water resources. One component of the hydrologic cycle that could be affected is evapotranspiration (*ET*), which could be altered because of the direct effects of CO_2 on stomatal conductance and on plant growth. Therefore, one important objective of the Free-Air CO_2 Enrichment (FACE) Project (See Kimball et al, this volume) is to evaluate the effects of elevated CO_2 on the *ET* of wheat.

APPROACH: The second of two replicate FACE experiments was conducted from December 1996 through May 1997. Four toroidal plenum rings of 25 m diameter constructed from 12" irrigation pipe were placed in a wheat field at Maricopa, Arizona, shortly after planting. The rings had 2.5-m-high vertical pipes with individual valves spaced every 2 m around the periphery. Air enriched with CO_2 was blown into the rings, and it exited through holes at various elevations in the vertical pipes. Wind direction, wind speed, and CO_2 concentration were measured at the center of each ring. A computer control system used wind direction information to turn on only those vertical pipes upwind of the plots, so that the CO_2-enriched air flowed across the plots no matter which way the wind blew. The system used the wind speed and CO_2 concentration information to adjust the CO_2 flow rates to maintain CO_2 concentrations at 200 ppm by volume CO_2 above ambient (about 360 ppm in daytime) at the centers of the rings. Four matching Blower rings with similar air flow but no added CO_2 were also installed the field.

In addition to the CO_2 treatments, varying soil nitrogen was also a factor in the this experiment. Using a split-plot design, the main circular CO_2 plots were divided into semi-circular halves with each half receiving either 350 (High N) or 15 (Low N) kg N/ha of NH_4NO_3 fertilizer through the drip irrigation system.

The determination of the effects of elevated CO_2 on *ET* by traditional chambers is fraught with uncertainty because the chamber walls that constrain the CO_2 also affect the wind flow and the exchange of water vapor. Therefore, a residual energy balance approach was adopted, whereby λET was calculated as the difference between net radiation, R_n, soil surface heat flux, G_0, and sensible heat flux, H; and where λ is the latent heat of vaporization.

$$\lambda ET = R_n - G_0 - H$$

R_n was measured with net radiometers, and G_0 with soil heat flux plates. H was determined by measuring the temperature difference between the crop surface and the air and dividing the temperature difference by an aerodynamic resistance calculated from a measurement of wind speed. Air temperatures were measured with aspirated psychrometers, and crop surface temperatures were measured with infrared thermometers (IRTs) mounted above each plot. Net radiometers, IRTs, psychrometers, cup anemometers, soil heat flux plates, and soil thermocouples were deployed in plots of all four treatments in Replicate 4, and net radiometers and IRTs were also deployed in Replicate 3 (which were redeployed to Replicate 2 after an unfortunate mix-up of nitrogen treatments in Replicate 3). Fifteen-minute averages were recorded on a datalogging system. The net radiometers and IRTs were switched weekly between the FACE and Blower plots.

FINDINGS: The micrometeorological data from the FACE Wheat 1996-7 experiment have not yet been analyzed, and "after experiment" calibrations of the infrared thermometers are currently underway. Findings from the first FACE x nitrogen experiment conducted in 1995-6 were reported in the 1996 USWCL Annual Research Report. Briefly, in that first experiment, the elevated CO_2 concentration in the FACE plots increased foliage temperatures by 0.6 and 1.1 °C at high and low N, respectively, during the daytime for much of the growing season. Soil heat flux was generally very small. Net radiation was the largest component of the energy balance, and sensible heat flux was moderate, so latent heat flux, λET, tended to follow net radiation. However, associated with the increases in foliage temperatures, there were small but consistent increases in sensible heat flux. FACE reduced daily totals of λET by about 6% at high N and 16% at low N. Moreover, the regression line at high N was very close to those from 1992-3 and 1993-4, which gives greater credence to the conclusion that enrichment to about 550 ppmv CO_2 reduces λET by about 6% at ample water and N. Of course, the results from 1996-7 are needed to confirm further (or deny) this conclusion.

INTERPRETATION: It appears from these data that irrigation requirements for wheat may be somewhat lower in the future high-CO_2 world (provided that any global warming is small).

FUTURE PLANS: The data from the 1996-7 FACE Wheat experiment will be analyzed, and the results will be reported. Then, starting in the summer of 1998, two replicate FACE Sorghum experiments will be conducted to evaluate the response of sorghum to FACE when soil water supply is limited. Micrometeorological parameters required to characterize the growing conditions in support of modeling efforts will be measured.

COOPERATORS: See report on "Progress and Plans for the Free-Air CO_2 Enrichment (FACE) Project."

SOIL WATER BALANCE AND WHEAT EVAPOTRANSPIRATION AS AFFECTED BY ELEVATED CO_2 AND VARIABLE SOIL NITROGEN

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PROBLEM: The Earth's rising atmospheric carbon dioxide (CO_2) concentration is expected to impact agricultural crop production worldwide. One concern is how increased levels of atmospheric CO_2 in the future will affect crop evapotranspiration (ET) and, thus, crop water requirements and irrigation management in the future. To date, only a few research studies have quantified ET for crops exposed to elevated CO_2 under natural, open-field conditions. Our objective was to evaluate crop ET, using soil water measurements, for wheat grown with CO_2-enriched air and variable soil nitrogen supply.

APPROACH: A Free-Air CO_2 Enrichment (FACE) system was installed within a 9-ha field at The University of Arizona, Maricopa Agricultural Center (MAC), to study the effects of elevated CO_2 on wheat cultivated in an environment representative of future agricultural fields. The 1996-97 FACE wheat experiment commenced with planting of Yecora Rojo, a spring wheat cultivar, on December 15, 1996, in flat beds at 0.25-m row spacings. As in previous FACE wheat studies, the FACE system was installed to enrich the atmospheric CO_2 concentration of four, circular plots (FACE plots), of 25-m diameter, to 550 μmol mol^{-1}, approximately 50% above the ambient concentration of 360 μmol mol^{-1}. Details on the MAC FACE system design, construction, and operation were previously reported in the 1992 through 1996 USWCL Annual Reports. Four circular control plots were also installed in the field, each plot approximately 90 m due east or west of one FACE plot, and were equipped with blowers to provide air movement across the plots similarly to that in the FACE plots. However, these plots (designated Blower plots) were not enriched with CO_2.

The FACE experimental design was a strip-split-plot with CO_2 the main effect, replicated four times. Each of the eight circular main plots was split into two semicircular subplots, where one subplot (designated High N) received an adequate supply of nitrogen fertilizer during the season while the other subplot (designated Low N) received a limited supply. All treatments were given 30 mm of water, applied by a portable sprinkler system on December 28, 1996, to moisten the seed bed for germination. Following crop establishment, subplots were irrigated with a subsurface drip system installed 0.18-0.25 m below the soil surface and at 0.5-m spacings between drip tubes. Irrigation scheduling for the wheat crop was determined with a meteorologically-based crop water use model (AZSCHED), developed by The University of Arizona, Agricultural and Biosystems Engineering Department. Meteorological data was provided by the MAC weather station located 2 km from the site. Water applications were given to all subplots at approximately 30% soil water depletion of the crop root zone, as determined with AZSCHED. Water application depths were the same in both High and Low N treatments until May when less water was applied to the Low N treatments to match the earlier senescence of that treatment. Four nitrogen chemigation applications during the season provided a total of 350 kg ha^{-1} N for the High N treatment. The Low N treatment received 15 kg ha^{-1} N, given with three applications.

Soil water contents were measured in all subplots on 35 days from December 19, 1996, through May 16, 1997. Time-Domain-Reflectometry equipment was used to measure soil water content in the top 0.3-m soil profile. Subsurface soil water contents (from 0.4 m to 2.0 m) were measured with a neutron scattering device in 0.2-m increments. Soil water contents were measured in subplots every four to nine days through February 1997. During March through May 1997 soil water contents were generally measured immediately prior to an irrigation and again two days after the irrigation. Average daily wheat ET was determined by the change in soil water storage over the estimated active rooting depth (1.3-m) divided by the number of days between soil water measurements. However, only those soil measurement sampling periods when water was not added by irrigation or heavy rainfall were used for average daily ET calculations. Average daily wheat ET during periods when irrigation or rainfall occurred was estimated from the measured daily ET rates immediately before and after the period.

FINDINGS: Total water applied from irrigation (excluding the initial 30 mm for crop establishment) was 591 mm for the Blower-High (BH) and FACE-High (FH) and 518 mm for the Blower-Low (BL) and FACE-Low (FL) treatments. The site received 16 mm of total rainfall during the growing season. Soil water content means for all treatments (Fig. 1) were high over the entire season, varying from about 50% available (≈65 mm of soil water depletion) to above field capacity. An irrigation scheduled for March 23, day of year 082 (DOY 082), was delayed until March 27 (DOY 086) due to a pump repair. From January through the end of April, BH generally had the higher average profile soil water contents of treatments, whereas FL had the lowest average soil water contents.

Figure 2 indicates that the mean cumulative ET was similar for all treatments until early April, at which time the low nitrogen treatments began to have reduced ET relative to the High N treatments. The total ET at the end of the season for the High nitrogen treatment was 621 mm for BH and was 602 mm for the FH, about 3% less ET than BH. The total ET was nearly equal for Blower and FACE Low N treatments, 505 and 509 mm, respectively. Analysis of variance indicated no effect on total ET due to CO_2 ($p<0.44$), a significant effect due to nitrogen ($p<0.01$), and no interaction ($p<0.65$).

Regression of average daily ET values for the FH with the corresponding values for BH (Fig. 3) resulted in a regression slope of 0.966, which was significantly different from 1.0 at the 0.01 probability level. This indicated there was a slight seasonal reduction in daily ET of about 3.4% due to CO_2 enrichment under the High N conditions. For the Low N treatment, regression of the data (Fig. 4) resulted in a slope of 1.004, which was not significantly different from 1.0 and indicated that there was no seasonal trend in ET due to CO_2 under Low nitrogen.

The 1996-97 results indicate a reduction in total ET on the order of 3% due to FACE under High N. Although not statistically significant according to analysis of variance, this result was consistent with a 4-5% decrease in total ET for FACE obtained with the same measurement technique in two earlier FACE wheat studies where the crop was grown under similar water and fertilizer conditions. As expected, low soil nitrogen caused a significant reduction in wheat ET. However, a reduction in ET due to FACE was not observed under the limited nitrogen treatment.

INTERPRETATION: For well-watered and well-fertilized wheat, crop evapotranspiration may be slightly lower under higher atmospheric CO_2 concentrations in the future, provided climate warming does not occur.

FUTURE PLANS: Evapotranspiration will be determined from soil water measurements in FACE grain sorghum studies that begin in 1998.

COOPERATORS: See FACE cooperator listing in "Progress and Plans for the Free-Air CO_2 Enrichment (FACE) Project," in this volume.

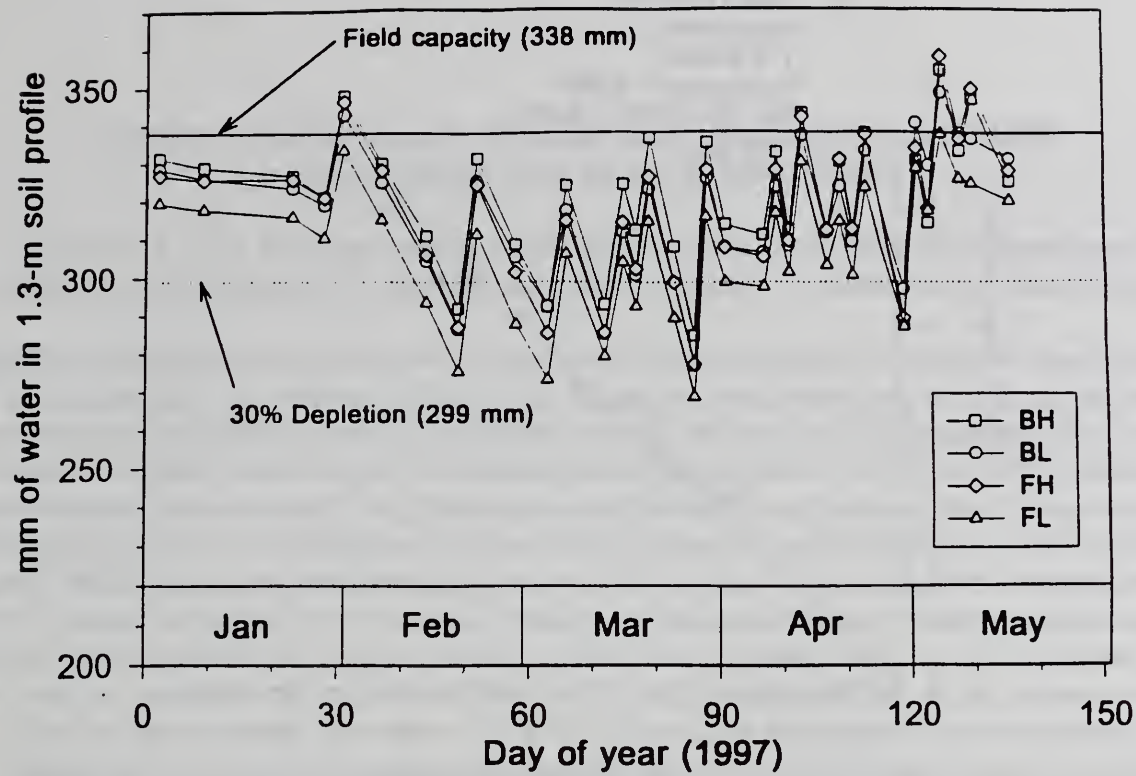

Figure 1. Treatment soil water content means with day of year in 1996-97.

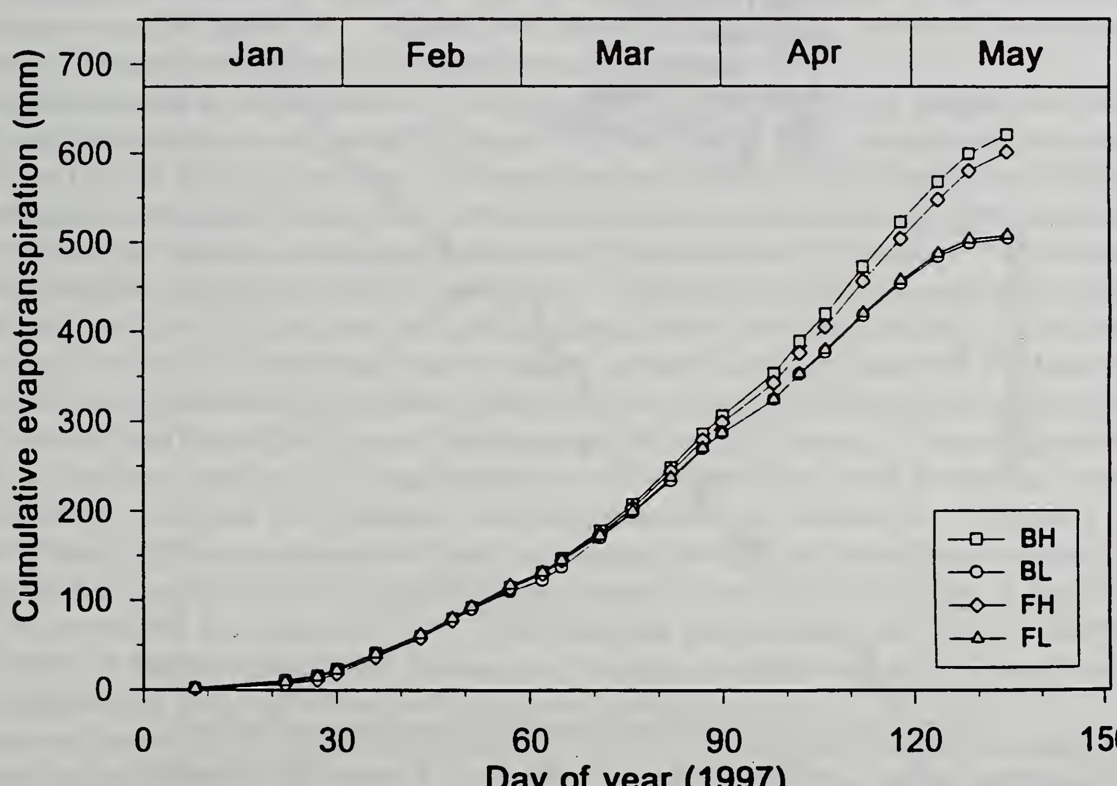

Figure 2. Treatment cumulative evapotranspiration with time 1996-97.

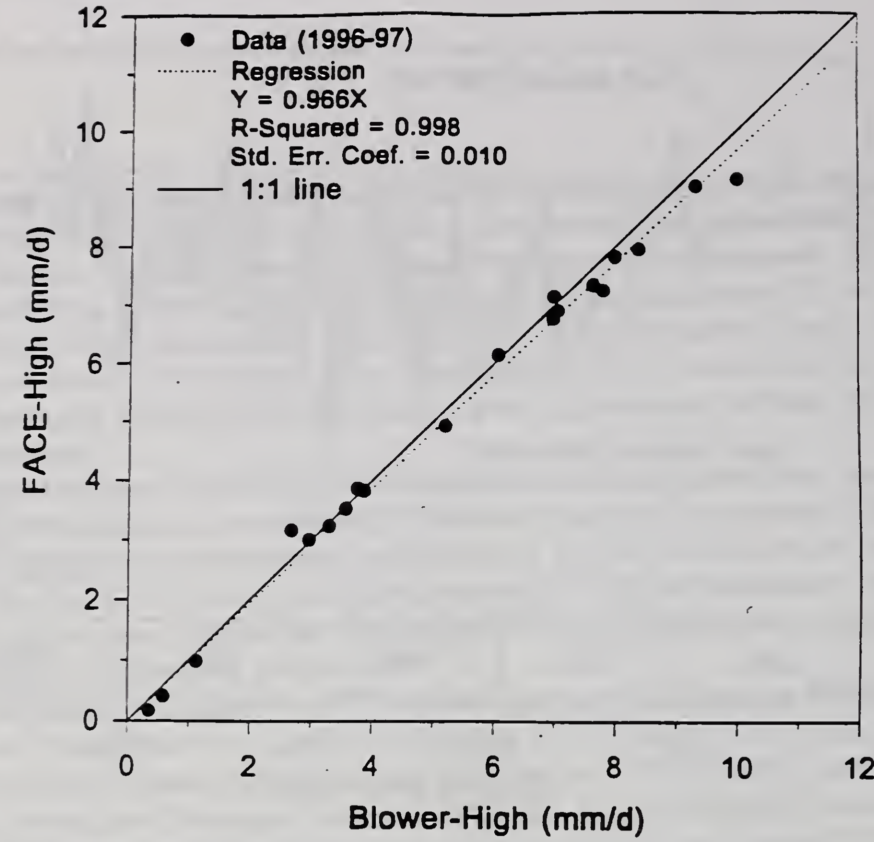

Figure 3. Regression results of the daily ET values for the FACE-High treatment with corresponding values for Blower-High, 1996-97.

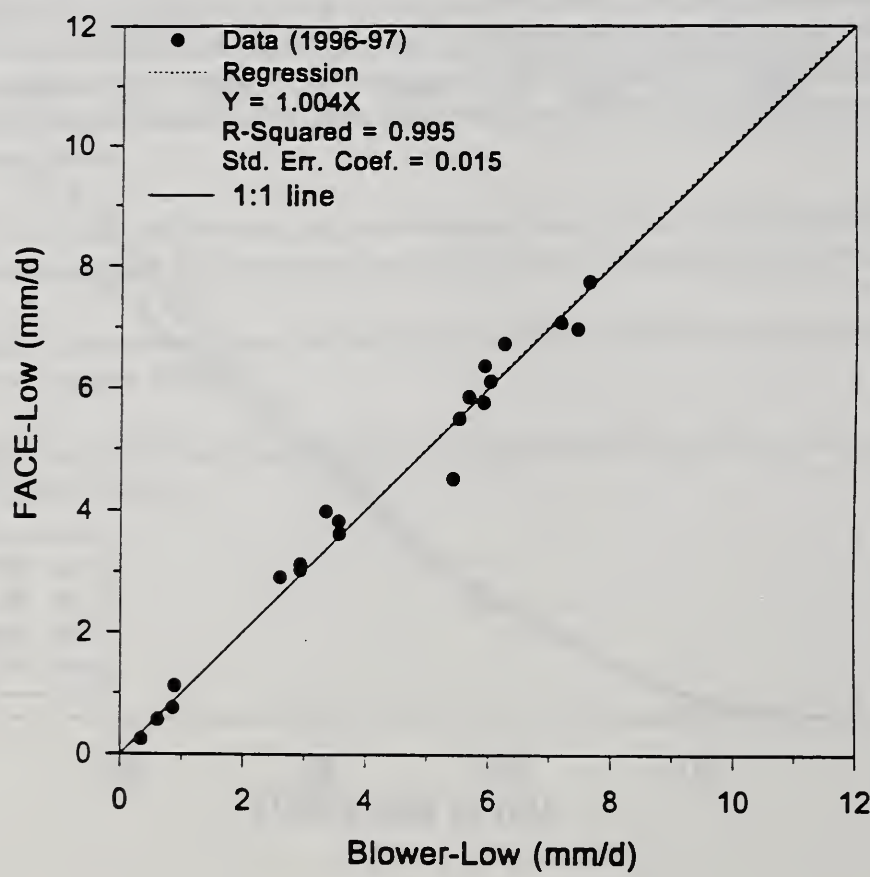

Figure 4. Regression results of the daily ET values for the FACE-Low treatment with corresponding values for Blower-Low, 1996-97.

EFFECTS OF ELEVATED CO_2 AND SOIL NITROGEN FERTILIZER ON FINAL GRAIN YIELDS OF SPRING WHEAT

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R. L. LaMorte, Civil Engineer; F. Adamsen, Soil Scientist; and D. J. Hunsaker, Agricultural Engineer

PROBLEM: Agricultural ecosystems will probably experience a significant increase in atmospheric CO_2 during the next century. The potential effect of this change on crop productivity is currently the subject of extensive research by USWCL scientists. Beginning in 1989, the Free Air CO_2 Enrichment (FACE) facility near Maricopa, Arizona, has been used to examine the interactive effects of CO_2 and other environmental stresses on both cotton and wheat in large fields typical of production agriculture. Our findings have shown that season-long exposure to ~550 µmol CO_2 per mol air caused an average increase of 40% in cotton lint yield and 8-15% in wheat grain yield, provided water was not limiting. When water stress was imposed on the plants, CO_2 stimulated productivity even more. However, in non-industrialized countries and in most natural ecosystems, nutrient availability is also expected to affect plant response to CO_2. Thus, during the 1995-96 season we began to examine the interactive effects of CO_2 and nitrogen fertilizer on the responses of spring wheat. Results from that study showed the CO_2 effect was smaller when plants also encountered nutrient stress. This report provides a second year of observations on the effect of CO_2 and nitrogen on wheat yields in the FACE facility.

APPROACH: Experiments were conducted at The University of Arizona, Maricopa Agricultural Center (MAC). A hard red, spring wheat (*Triticum aestivum*, L. cv Yecora Rojo) was sown on December 15, 1996, in EW oriented rows with 0.25 m spacing. The seeding rate was 111 kg ha^{-1} (~252 seeds m^{-2}); plant density at emergence was 194 plants m^{-2}. Irrigation, via subsurface drip tubing, was based on estimates of daily potential evaporation multiplied by a crop coefficient for wheat.

Plants were exposed to control (Blower, ~360 µmol mol^{-1}) and enriched (FACE, ambient plus 200 µmol mol^{-1}) CO_2 levels; treatments were replicated four times. Plots were positioned in the same field locations that were used for the 1995-96 FACE experiment. Enrichment began on January 3, 1997, two days after 50% emergence of seedlings, and continued 24 hours a day with minimal interruptions until May 12, 1997. As in the 1995-96 FACE experiment, controls were equipped with blower fans similar to FACE arrays. Plots without blowers were not established during the 1996-97 experiment. CO_2 treatment plots were split to test High (350 kg $season^{-1}$ ha^{-1}) and Low (15 kg $season^{-1}$ ha^{-1}) nitrogen applications. Fertilizer (NH_4NO_3) was delivered via the drip irrigation system at mid-tillering, stem extension, anthesis, and early grain fill. The High N treatment received 621 mm irrigation during the season, while the Low N treatment (faster maturing) received 548 mm. Plants were sampled from all replicates of each treatment at weekly intervals (17 sampling periods). Crown, stem, green and non-green leaf, and head components were separated and dried for biomass determinations. Plant phenology, green leaf and green stem areas were measured on a subsample. Developing grains were separated from chaff by a combination of hand and machine threshing of heads that were pooled by subplot. Final grain yield was determined by harvest of approximately 18 m^2 area of each plot on May 28-29, 1997. Grain was oven-dried for 14 days at 70 °C. Yield data were analyzed using the ANOVA GLM procedures of the Statistical Analysis System (SAS Institute, Inc.). A split-plot model was used which included CO_2 (main plot), nitrogen (split plot), replication, and appropriate interaction terms.

Canopy reflectance factors (Red, 0.61-0.68 µm; NIR, 0.79-0.89 µm) were measured frequently throughout the season using a handheld radiometer at a morning time corresponding to a solar zenith angle of 57°. A normalized difference vegetation index (NDVI) was computed as (NIR-Red)/(NIR+Red).

FINDINGS: Seasonal trends in NDVI revealed large differences between High and Low N treatments in the amount and persistence of photosynthetically active biomass (Fig. 1). End-of-season patterns of NDVI in the High N treatments were similar in Blower and FACE treatments, implying that CO_2 *per se* had minimal effect

on rates of overall canopy development or senescence. There was only a slight increase in senescence rates caused by elevated CO_2 in the Low nitrogen treatment. The final grain yields from individual plots displayed considerable variation within treatments (fig 2). As observed in previous experiments, yields from the NW corner of the field (replicate 1) tended to be slightly higher than yields from other plots. A fertilizer treatment mix-up was detected via routine chlorophyll meter readings (SPAD 502, Minolta Corp.) in replicate 3 during the stem extension period (March 18, 1997). This undoubtedly contributed to the high yields in the Blower Low N treatment of replicate 3. As a result of the fertilizer error, all analyses exclude data from replicate 3.

Final harvests from the recent experiment ranged from 5 Mg ha^{-1} (Blower, Low N) to more than 7 Mg ha^{-1} (FACE, High N). Although these yields were slightly lower than those obtained during the three previous FACE wheat experiments(table 1, Fig. 3), they still remained relatively high when considering county production records. During the 1996-97 season, we found that elevated CO_2 stimulated grain production by 17% when nitrogen was not limiting. The Low N treatment reduced yields about 22% compared with their High N counterparts. Elevated CO_2 increased yields by only 5% in the Low N treatment. ANOVA revealed that the overall differences between CO_2 and Nitrogen treatment means were statistically significant at $p=0.046$ and $p<0.01$, respectively. However, the interaction between CO_2 and N was not statistically significant ($p=0.18$).

INTERPRETATION: Yield results show that the stimulatory effects of elevated CO_2 under non-limiting nutrient and water conditions were about half again as high during 1995-96 and 1996-97 (+16%) than in our first two years of experiments (+10%). Part of this may have been caused by slightly different control strategies for the elevated CO_2 treatment (*i.e.*, a nominal +200 µmol mol^{-1} above ambient as opposed to a fixed 550 µmol mol^{-1}). However, a second and more plausible explanation for the differential response to CO_2 focuses on whether or not fans were present on the Control treatments. Compared with the FACE plots, we found slightly lower nighttime canopy temperatures, slower development, and delayed senescence in Control plots prior to equipping them with blowers. This provided plants in the Control treatments during 1992-93 and 1993-94 with a longer and greener grain filling period and a chance to "catch up" with faster-maturing FACE plants. During 1995-96 and 1996-97, all treatment plots had fans enabling a more valid comparison between FACE and control CO_2 levels.

Seven years of research under realistic field conditions afforded by FACE technology has demonstrated that elevated levels of atmospheric CO_2 will increase the productivity of several important C_3 food and fiber crops. For spring wheat crops grown under optimum water and nutrient conditions, our data show that grain yields will probably rise by 16% if CO_2 levels increase 200 µmol mol^{-1} above ambient levels. Elevated CO_2 will also produce early and mid-season increases in GLAI and fAPAR. The response to CO_2 appears to be increased when plants encounter moderate water stress -- good news for farmers in drought stricken regions of the world. However, when limited nitrogen supplies reduce yields below potential levels, the beneficial effects of CO_2 also appear diminished.

FUTURE PLANS: Agronomic data from the weekly samples are still being analyzed. FACE experiments utilizing grain sorghum (a C_4 crop) are presently planned for the 1998 and 1999 seasons.

COOPERATORS: We wish to acknowledge the collaborative efforts of S. Leavitt, A. Matthias, T. Thompson, and S. White of The University of Arizona; B. Roth, P. Murphree, J. Chernicky, and R. Rauschkolb from MAC; K. Lewin, J. Nagy, and G. Hendrey from Brookhaven National Laboratory; and F. and G. Wechsung, S. Grossman, and T. Kartschall from the Potsdam Institute for Climate Research. We also thank R. Rokey, S. Gerszewski, R. Seay and D. Pabian for technical assistance in the field and R. Altamarano, M. Baker, C. O'Brien, H. Stierman, and K. West for processing the plant samples.

Table 1. Final grain yields (Mg dry wt/ha) and CO2 enhancement factors (calculated as the ratio of FACE to Control yields) of spring wheat grown in the FACE research facility at MAC during 4 seasons. Probability refers to the likelihood of obtaining a larger F statistic when comparing indicated treatment means or interactions between treatments using the General Linear Model Procedure (SAS).

YEAR	High N, Ample Irrig Yield (Mg/ha)			High N, Deficit Irrig Yield (Mg/ha)			Low N, Ample Irrig Yield (Mg/ha)			Probability			
	FACE	CON	F:C	FACE	CON	F:C	FACE	CON	F:C	CO2	Irr	N	Inter.
1992-93	9.04	8.37*	1.080	7.20	5.95*	1.210	—	—	—	0.036	<0.001	—	0.102
1993-94	8.31	7.44*	1.117	5.92	4.74*	1.249	—	—	—	0.062	0.008	—	0.489
1995-96	8.49	7.40	1.148	—	—	—	6.46	5.77	1.119	0.058	—	0.002	0.387
1996-97	7.16	6.13	1.168	—	—	—	5.31	5.04	1.052	0.045	—	0.004	0.177

* Indicates that control plots were not equipped with fans (1992-93 & 1993-94).

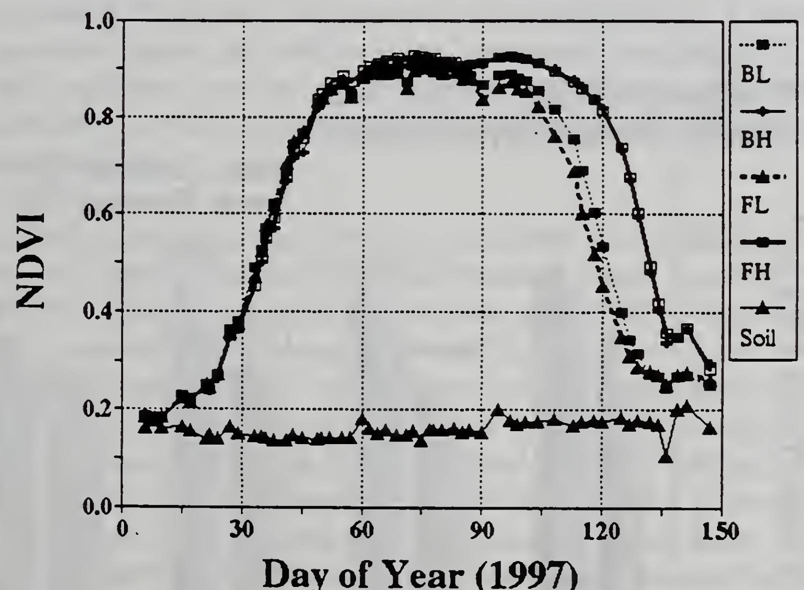

Figure 1. Seasonal trajectory of the normalized difference vegetation index (NDVI) measured during the 1996-97 FACE wheat experiment. Data represent treatment means of 3 replicates of Blower Low N (BL), Blower High N (BH), FACE Low N (FL), and FACE High N (FH). Also shown are NDVIs from an unvegetated soil plot.

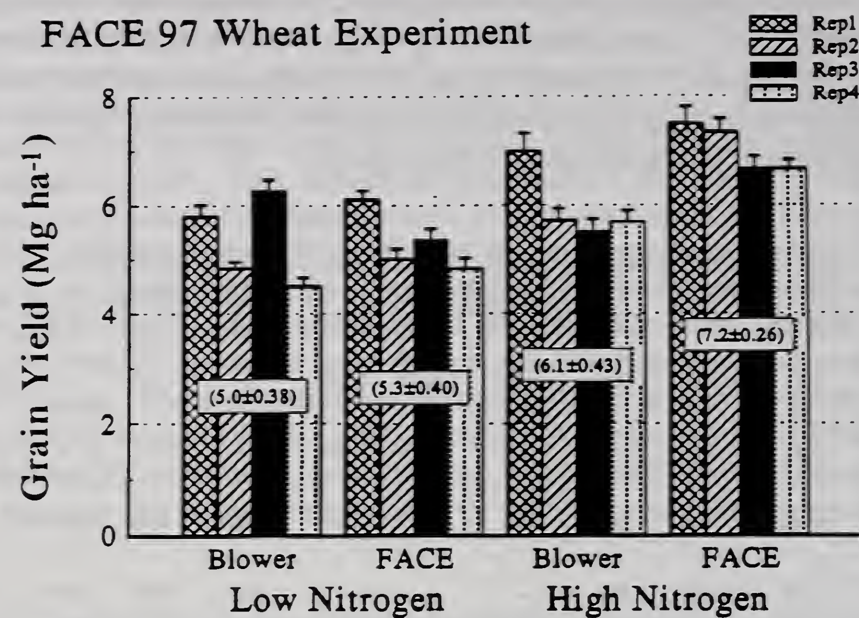

Figure 2. Final harvest data from the 1996-97 FACE experiment at MAC. Data are shown for individual replicates. Values given in parentheses represent mean and std error for Reps 1, 2, and 4.

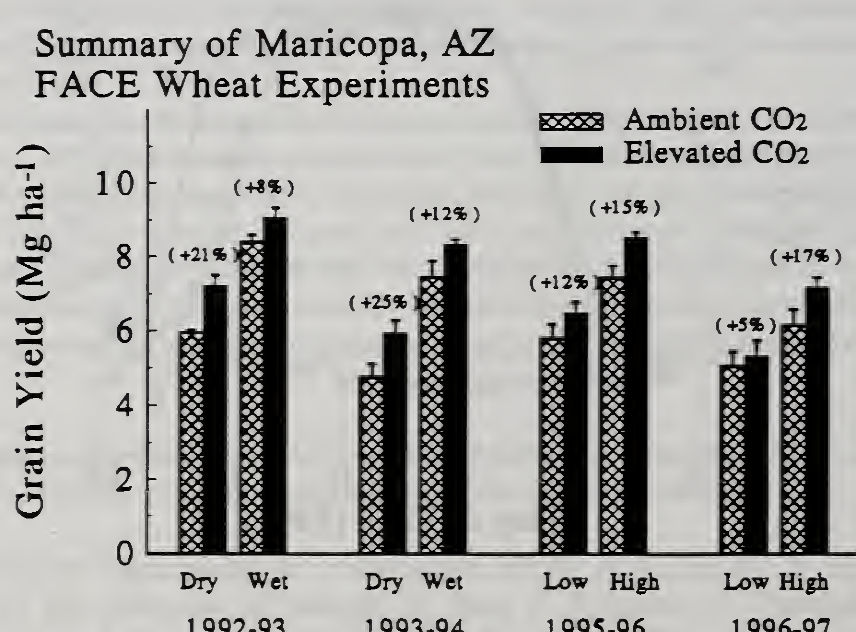

Figure 3. Final harvest data from 4 FACE wheat experiments conducted at MAC between 1992 and 1997. Percentages in parentheses above bars indicate relative CO_2 enhancement.

CHANGES IN PHOTOSYNTHETIC APPARATUS OF SPRING WHEAT IN RESPONSE TO CO_2-ENRICHMENT AND NITROGEN STRESS

N. R. Adam, Plant Physiologist; G.W. Wall, Plant Physiologist; T. J. Brooks, Research Assistant; T.D. Lee, Biological Science Technician; B.A. Kimball, Soil Scientist; P.J. Pinter Jr., Research Biologist; and R.L. LaMorte, Civil Engineer

BACKGROUND: With the expected doubling of atmospheric levels of CO_2 by sometime in the 21st century, it is important to understand how this change will affect our way of life and, more specifically, how it will affect plant life. Much research has been conducted to determine how plants respond and acclimate to long-term exposure to elevated levels of CO_2 in the field. The Free Atmospheric CO_2 Enrichment (FACE) facility at The University of Arizona, Maricopa, Agricultural Research Center, is helping to address this question. A compilation of the Maricopa FACE data from 1995 and 1996 showed that elevated CO_2 caused final wheat grain yields to rise by an average of 13% under non-limiting water and nutrient conditions (see Pinter *et al.* this publication). However, under lower levels of nitrogen, CO_2 enrichment increased yields by 8%. It is important to investigate whether further increases in atmospheric CO_2 may result in further yield increases.

Plants acclimate to changes in CO_2 concentration through the process of photosynthesis. This long-term, acclimatory response of photosynthesis can involve regulation of the amount and activity of enzyme required to reestablish a balance within the photosynthetic apparatus. A gas-exchange technique in which photosynthesis (A) is measured at a range of intracellular CO_2 concentrations (Ci) can provide information on these changes. Since Rubisco (the enzyme catalyzing the initial reaction of photosynthesis) capacity is limiting at low values of Ci, the slope of the A-Ci relationship at those low values of Ci can be used to assess changes in the ability of Rubisco to fix CO_2. This slope can therefore be called the "carboxylation efficiency". A decrease in the slope of this line is an indicator of down-regulation, in which the amount of Rubisco is decreased in response to the greater concentration of atmospheric CO_2. If down-regulation does occur, we could expect an upper limit to the yield increases commonly seen under CO_2 enrichment. Therefore, the objective of this experiment was to use the A-Ci relationship to investigate possible changes in the carboxylation efficiency of wheat as a result of CO_2 enrichment and nitrogen stress and to determine whether down-regulation is occurring.

APPROACH: Hard red spring wheat (*Triticum aestivum* L. cv. Yecora Rojo) was planted in an open field at The University of Arizona Maricopa Agricultural Research Center, located 50 km south of Phoenix, Arizona (33.1 °N, 112.0 °W). Wheat was sown into flat beds at 0.25-m row spacing on December 15, 1996 at a population of 194 plants m^{-2}, 50% emergence occurred January 1, 1997, and the crop was harvested May 28-29, 1997. Following sowing, a FACE apparatus was erected on site to enrich the CO_2 concentration of the ambient air (ca. 370 μmol mol^{-1}) to ca. 570 μmol mol^{-1}. Nitrogen was applied as a split plot factor using subsurface drip irrigation such that high N plots received 350 $kg \cdot ha^{-1}$ and the low N plots received 70 $kg \cdot ha^{-1}$.

Beginning with tillering, clumps of wheat plants were dug from each treatment in each of three replications, placed in water in plastic bags and stored in a cool room until measurement. Just prior to measurement, the uppermost-fully expanded leaf (referred to as flag leaf), flag minus one and flag minus two, were excised under water and placed under halogen lights until measurement. Photosynthesis rates were measured over a range of intracellular CO_2 levels, generating an A-Ci curve. At the end of each curve, the leaf was frozen as quickly as possible with a liquid nitrogen-cooled clamp and stored in liquid nitrogen for later biochemical analyses.

The initial slope of the A-Ci curve was used as an estimate of the carboxylation efficiency, which is defined as the ratio of the change in photosynthesis over the change in Ci at low values of Ci. Although data analysis is not complete, analysis of the slopes as means in a General Linear Model (GLM) provided a preliminary analysis of the data. Data were grouped into growth stages for interpretation.

FINDINGS: For the flag leaf, significant N effects were seen during tillering and stem extension and both CO_2 and N effects were seen during the milk dough stage (figure 1a). No treatment patterns were evident during boot, heading or anthesis. The flag minus one leaf showed a significant N*CO_2 interaction for anthesis and significant N, CO_2 and N*CO_2 effects during milk dough (figure 1b). Significant N effects were seen for flag minus two during heading and anthesis (figure 1c). In general, leaves from the FACE treatments had lower (or equal, in the case of the flag leaf) carboxylation efficiencies than did leaves in the control treatments, and leaves in the low N treatments had lower carboxylation efficiencies than leaves in the high N treatments. Though treatment patterns indicating down-regulation (i.e., lower carboxylation efficiencies in FACE, and especially in FACE-high N) were not evident in the flag leaf, flag minus one and flag minus two showed greater evidence of this phenomenon. The high variability in the data prevents high confidence levels, but the trends indicate the following: in general, it appears that down-regulation does not occur in the flag leaf. However, it does appear to be more important in the lower leaves, indicating that the effect of CO_2 enrichment on plants may be realized through the responses of leaves lower in the canopy.

INTERPRETATION: The indications of down-regulation in wheat suggest that there may be an upper limit on the yield increases of wheat that have been measured under higher atmospheric CO_2 concentrations.

FUTURE PLANS: Further refinement of the gas exchange data analysis will be carried out. In addition, biochemical assays will be conducted on the freeze-clamped leaves which should lend support to the gas exchange data and add information that will aid in the interpretation of the data.

COOPERATORS: We wish to acknowledge the collaborative efforts of Steve Leavitt, Alan Matthias, and Tom Thompson of The University of Arizona; Andrew Webber of Arizona State University; Bob Roth, Pat Murphree, Jon Chernicky, and Roy Rauschkolb from the Maricopa Agricultural Center; Keith Lewin, John Nagy, and George Hendrey of Brookhaven National Laboratory; and Frank and Gabrielle Wechsung and Thomas Kartschall from the Potsdam Institute for Climate Research. We also thank Jose Olivieri for technical assistance.

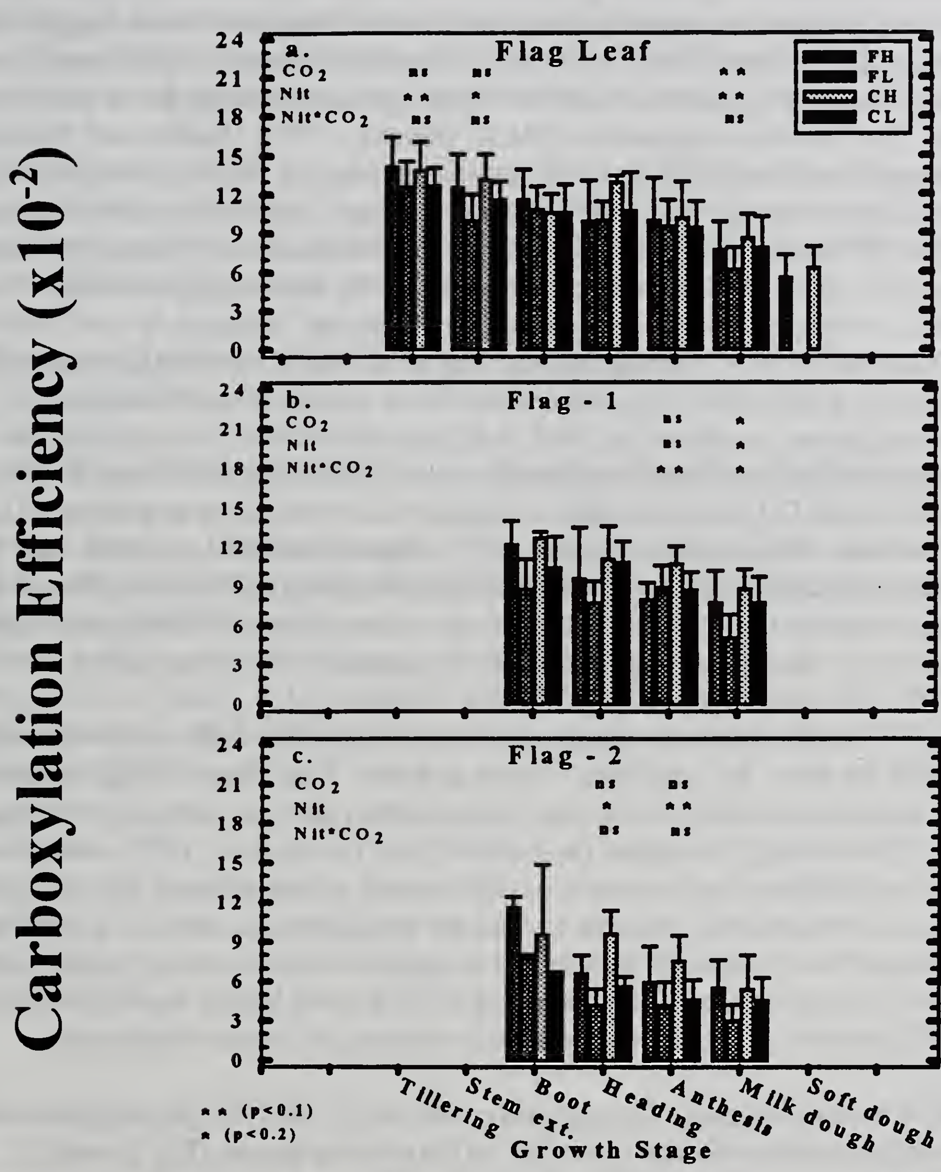

Figure 1. Carboxylation efficiencies by growth stage for (a) Flag leaf, (b) Flag leaf minus one, and (c) Flag leaf minus two. Treatments are FACE- High N (FH), FACE-Low N (FL), Control-High N (CH) and Control-Low N (CL). One asterisk indicates a probability level of $\alpha<0.2$ and two asterisks indicate a probability level of $\alpha<0.1$.

EFFECTS OF NITROGEN AND CO_2 ON WHEAT CANOPY ARCHITECTURE AND GAS EXCHANGE

T.J. Brooks, Research Technician; G.W. Wall, Plant Physiologist; P.J. Pinter, Jr., Research Biologist; N. Adam, Plant Physiologist; B.A. Kimball, Soil Scientist; R.L. LaMorte, Civil Engineer; F.J. Adamsen, Soil Scientist; and D.J. Hunsaker, Agricultural Engineer

PROBLEM: The Intergovernmental Panel on Climate Change (IPCC) reports that global CO_2 levels will rise from the current ambient level of 370 μmol mol $^{-1}$ to over 500 μmol mol $^{-1}$ by the end of the 21 st century (IPCC, 1995). Of primary concern to the human population is the impact that rising global CO_2 concentrations will have on agriculture. The USWCL Environmental and Plant Dynamics (EPD) group has been investigating the impact of increased CO_2 and water stress on various agricultural crops for the past 8 years through the use of a Free-Air CO_2 Enrichment apparatus (FACE) (Hendrey, 1993; Hendrey and Kimball, 1994). Previous FACE experiments used small (1m ^{2}) pop-on chambers to measure the rates of net photosynthesis and canopy conductance, therby providing "snapshots" of crop physiology. Results from these investigations have enabled members of the EPD group to conclude that canopy photosynthesis and water use efficiency are improved in C3 plants, such as wheat and cotton, when subjected to CO_2 enriched environments (Kimball *et al.,* 1995). The net effect of these CO_2-based responses are substantial increases in yield with slightly less water consumed. The FACE 1995-7 investigation seeks to understand if improved plant growth and yield will hold true when wheat is grown under CO_2-enriched conditions with limiting soil nitrogen.

Previous investigations conducted by Wall et al (unpublished data) investigating the effects of CO_2 and limiting soil nitrogen indicate that photosynthesis rates of wheat flag leaves may be enhanced by as much as 32% for well fertilized CO_2 enriched plants, compared with those grown at ambient CO_2 and inhibited by as much as 27% when nitrogen stressed plants were compared with CO_2 enriched, well fertilized plants. In contrast, preliminary canopy photosynthesis data obtained during the 1996 FACE experiment indicated only 12% enhancement due to CO_2 and 15% reduction due to nitrogen stress. These canopy data were in agreement with the grain yield. Mechanisms responsible for the reduction of treatment effect were investigated.

APPROACH: Four 25-m-diameter rings were placed in the field and used to continually enrich the CO_2 concentration of the air to 200 μmol mol $^{-1}$ above ambient. Four identical rings served as controls. Ample nitrogen was applied to one half of each ring, while the other half was subjected to nitrogen stress (strip-split plot design). "Flow-through" chambers (as modified from Garcia et al., 1994) were placed in each treatment for one of the four replicates and were used to collect canopy carbon exchange data for a period of 72-96 hours. The chambers were moved from replicate to replicate throughout the course of a growing season. Resulting data were analyzed for differences in both diurnal and temporal trends in canopy photosynthesis. Supplemental measurements of canopy greenness, plant area index (PAI), mean leaf tip angle distribution (MTA), and solar radiation (PAR) aided in generating a general understanding of canopy development.

FINDINGS: Wheat grown under CO_2 enriched conditions for the 1997 growing season exhibited a doubling of daytime canopy carbon exchange rates early in the growing season (Fig. 1c and 2). As in 1996, at stem elongation when the canopy closed CO_2 had no effect. This may be due to, in part, the cutting off of light to lower photosynthetically active leaves. At canopy closure, green leaf area index (GLAI, as may be interpreted from Fig. 4) reaches a steady state condition. From stem elongation forward, the CO_2 effect increases in magnitude, reaching 14% at early milk. Senescence effects confound interpretation for the remainder of the season. Though difficult to interpret due to variability within the plots, nitrogen stress in CO_2 enriched plots may have more significantly reduced temporal canopy carbon accumulation than in ambient CO_2 plots (Fig. 2), as indicated at boot, anthesis, and soft dough. Treatment-based changes in canopy architecture and age were apparent, as indicated by differences in canopy greenness, LAI, and MTA (figs. 3, 4, and 5). Though analysis of LAI and MTA for 1997 has not been completed, preliminary computations indicate that the trends for the

previous year are very similar. Temporal trends indicated that these effects were present throughout the entire growth season, although early season data indicated that the effects were more predominant after tillering.

INTERPRETATION: Though diminished when compared with flag leaves, canopy photosynthesis responded to CO_2 and nitrogen stress as expected. Ample nitrogen, CO_2 enriched canopies accumulated the most carbon, whereas nitrogen stressed, ambient CO_2 accumulated the least. Nitrogen stressed, CO_2 enriched and ample nitrogen, ambient CO_2 were intermediate in their response. Response to CO_2 enrichment was greatest early in the season. After stem elongation, the re-emergence and strengthening of CO_2 effects suggest that changes in canopy morphology may enhance canopy radiation use efficiency. In turn, improved canopy radiation use efficiency allows greater carbon accumulation than that which would be possible if architecture were uniform across all treatments. The increases in canopy carbon gain through enhanced canopy radiation use efficiency provide a potential mechanism for diminishing the dramatic treatment effects found in the individual leaf data.

FUTURE PLANS: Data analysis is still in progress. Canopy light use efficiency for each treatment will be determined and used to determine the effect of changing canopy morphology with respect to CO_2 and nitrogen treatment. Preparations are under way to conduct a replicated investigation of canopy photosynthesis and architecture in the 1998 FACE sorghum experiment.

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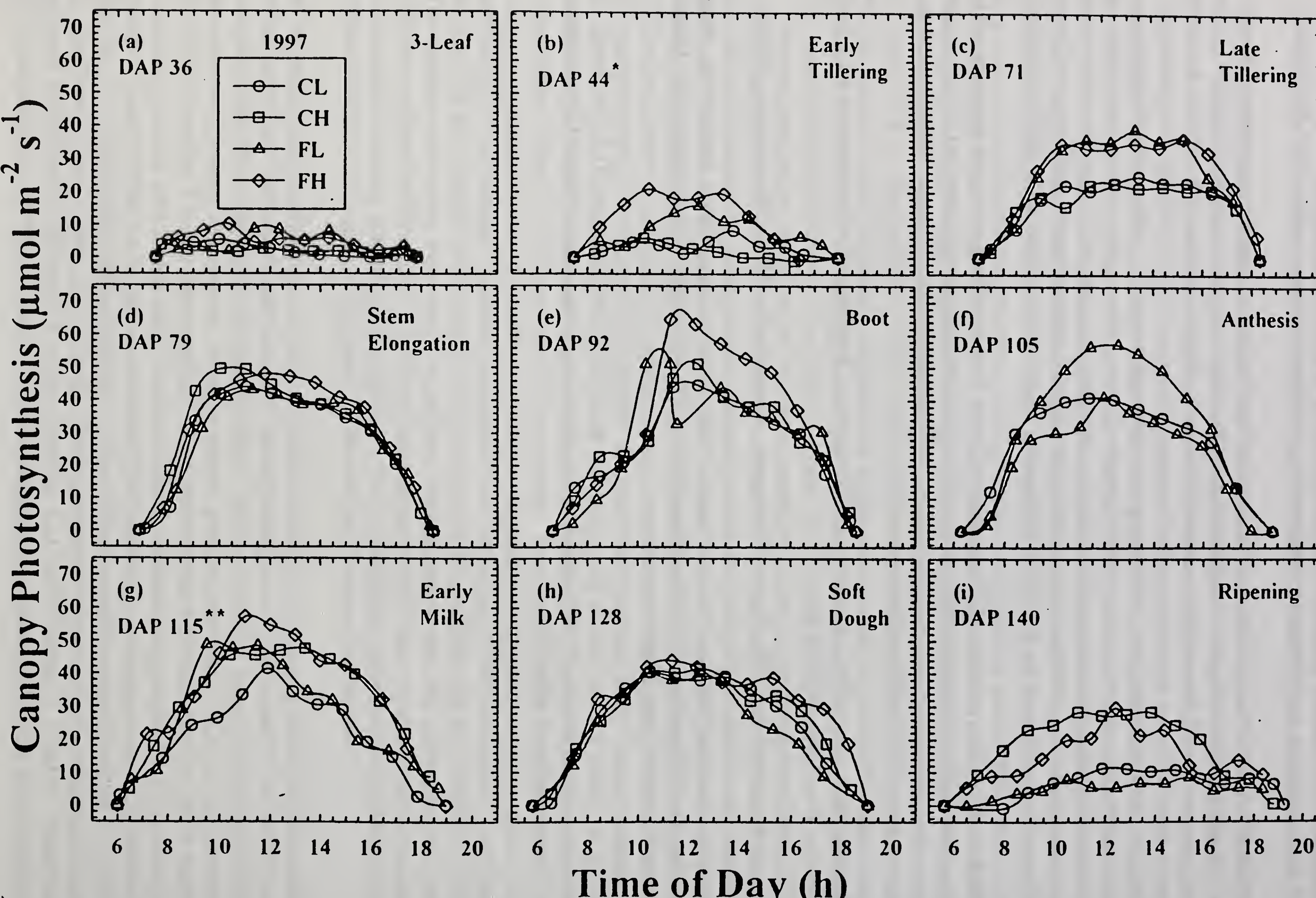
Figure 1.



* Data split between DAP 44 and 45. ** Data split between DAP 115 and 117. For both cases, days sampled are meteorologically similar.

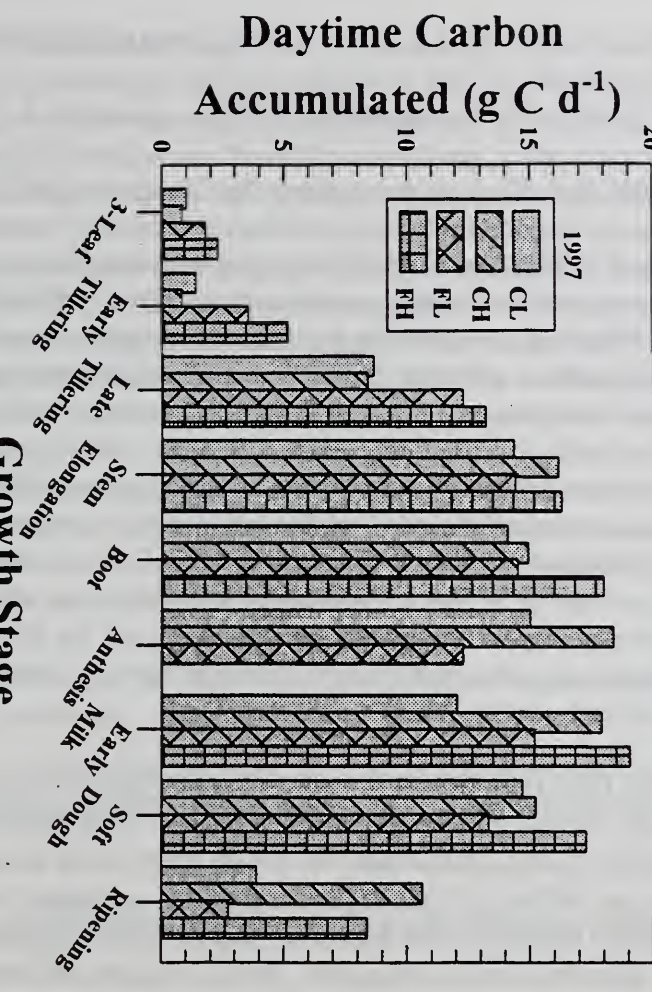


Figure 2.

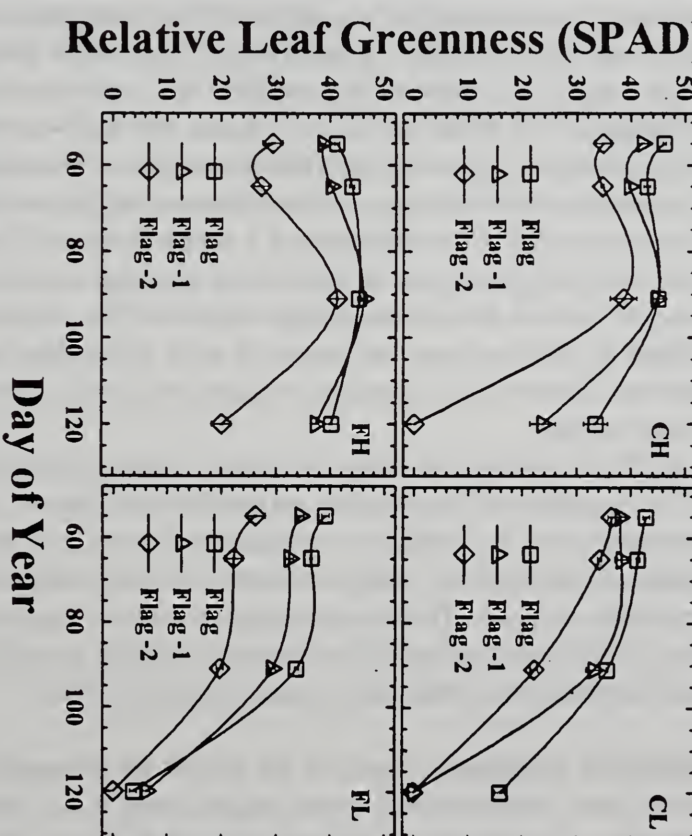


Figure 3.

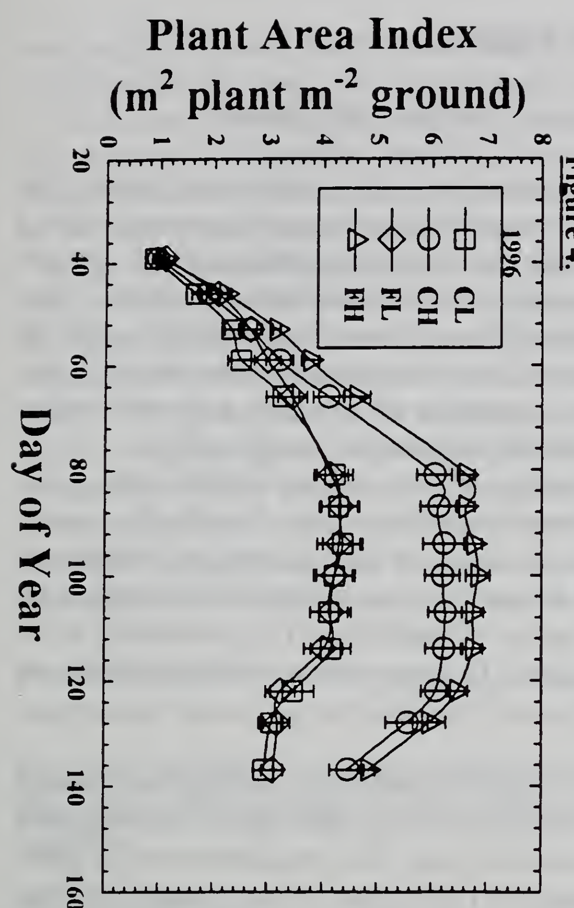


Figure 4.

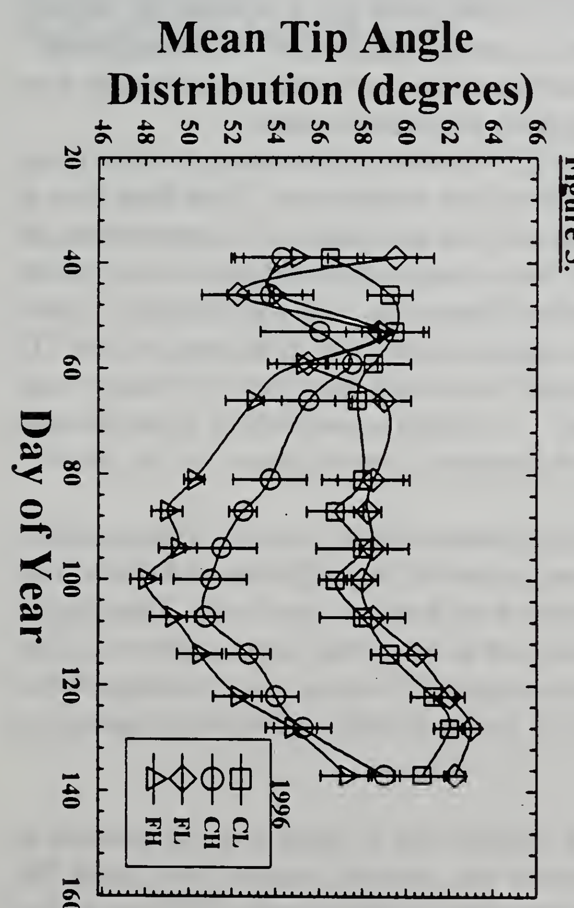


Figure 5.

CO_2 ENRICHMENT OF TREES

S. B. Idso, Research Physicist; and B. A. Kimball, Supervisory Soil Scientist

PROBLEM: The continuing rise in the CO_2 content of Earth's atmosphere is believed by many people to be the most significant ecological problem ever faced by humanity because of the widespread assumption that it will lead to catastrophic global warming via intensification of the planet's natural greenhouse effect. Largely unknown, however, are the many beneficial effects of elevated atmospheric CO_2 concentrations on Earth's plant life. Hence, it is imperative that this other aspect of atmospheric CO_2 enrichment be elucidated so that the public can have access to the full spectrum of information about the environmental consequences of higher-than-ambient levels of atmospheric CO_2. Only under such conditions of complete and wide-ranging understanding can the best decisions be made relative to national and international energy policies.

As forests account for two-thirds of global photosynthesis, and are thus the primary players in the global biological cycling of carbon, we have chosen to concentrate on trees within this context. Specifically, we seek to determine the direct effects of atmospheric CO_2 enrichment on all aspects of their growth and development; and we hope to be able to determine the ramifications of these direct effects for global carbon sequestering, which may also be of considerable significance to the climatic impact of atmospheric CO_2 enrichment, as the biological sequestering of carbon is a major factor in determining the CO_2 concentration of the atmosphere and the ultimate level to which it may rise.

APPROACH: In July 1987, eight 30-cm-tall sour orange tree (*Citrus aurantium* L.) seedlings were planted directly into the ground at Phoenix, Arizona. Four identically-vented, open-top, clear-plastic-wall chambers were then constructed around the young trees, which were grouped in pairs. CO_2 enrichment--to 300 ppmv (parts per million by volume) above ambient--was begun in November 1987 to two of these chambers and has continued unabated since that time. Except for this differential CO_2 enrichment of the chamber air, all of the trees have been treated identically, being irrigated and fertilized as deemed appropriate for normal growth.

Numerous measurements of a number of plant parameters have been made on the trees, some weekly, some monthly, and some annually. Results of our most recent findings are summarized below.

At the conclusions of the second and third full years of our study, we measured the diameters of the trunks and branches of all of the trees at their bases and at 20-cm intervals out to their ends. From these data we calculated the total volume of trunk and branch tissue comprising each tree and compared the results with each tree's trunk cross-sectional area -- an easily measured parameter that we assess at the mid-point of each month. This exercise revealed the existence of a simple linear relationship between the cube root of trunk + branch volume and the square root of trunk cross-sectional area that applies equally well to all trees of both CO_2 treatments; and we have subsequently employed this relationship to estimate the volume of woody tissue produced by all trees over the course of each succeeding year. To obtain an estimate of actual biomass production, however, it is necessary to know the density of each treatment's woody tissue; i.e., its dry mass per fresh volume.

In an effort to obtain this vital information, we have recently begun measuring the volumes of large numbers of 10-cm segments of branches that we are forced to remove from portions of the peripheries of the trees when they impinge upon the walls of the enclosures in order to keep them from destroying the walls. These branch segments are subsequently dried in ovens for several weeks to drive off all water they contain, after which they are carefully weighed. The results are then used to compute each segment's final dry mass per original fresh volume, in the hope that we will ultimately assemble enough such data to be able confidently to convert our bio*volume* production data into bio*mass* production data.

FINDINGS: Preliminary results of our efforts are presented in figures 1 and 2, where it can be seen that for branches with cross-sectional areas ranging from 0.3 to almost 4 cm^2, branch densities within both CO_2 treatments are relatively independent of branch thickness. The upper boundaries of both of the data sets are

also roughly the same; but the lower boundary of the ambient-treatment data set extends far below that of the CO_2-enriched treatment. As a consequence of this phenomenon, the mean density of the CO_2-enriched wood is 5.8% greater than that of the ambient wood, and it is also more uniform. We must still obtain results for significantly larger branches; and this we periodically do when such a branch poses a threat to the integrity of the enclosure walls. It is our hope that we will have obtained enough such data to present our final conclusions on this topic in next year's Annual Report.

At the conclusion of last year's harvest, when we picked over three times more fruit from the CO_2- enriched trees, we also determined the fractional dry weight of fifty randomly-selected oranges from each tree, so we can ultimately evaluate the total dry weight of fruit removed from the trees each year from simple fresh weight measurements. Our initial results indicate that the mean fractional dry weight of the CO_2-enriched fruit is about 3.2 % greater than that of the ambient-treatment fruit. However, we will await a second year's results before settling on figures to use in further calculations.

As always, we will continue to measure the fresh and dry weights of 68 leaves from each of the trees at two-month intervals. Hence, we will soon be able to combine the dry weights of all of these different components of plant dry matter production in a way that will allow us to compare the total above-ground productivities of the trees of the two CO_2 treatments. Look us up next year for the thrilling results!

INTERPRETATION: Our findings continue to demonstrate that CO_2 is an effective aerial fertilizer, significantly enhancing the quality of various tree properties.

FUTURE PLANS: We hope to continue the sour orange tree experiment for three to four more years, or as long as is needed for them to achieve the nearly steady yearly growth rates that are characteristic of full maturity.

COOPERATORS: U.S. Department of Energy, Atmospheric and Climate Research Division, Office of Health and Environmental Research.

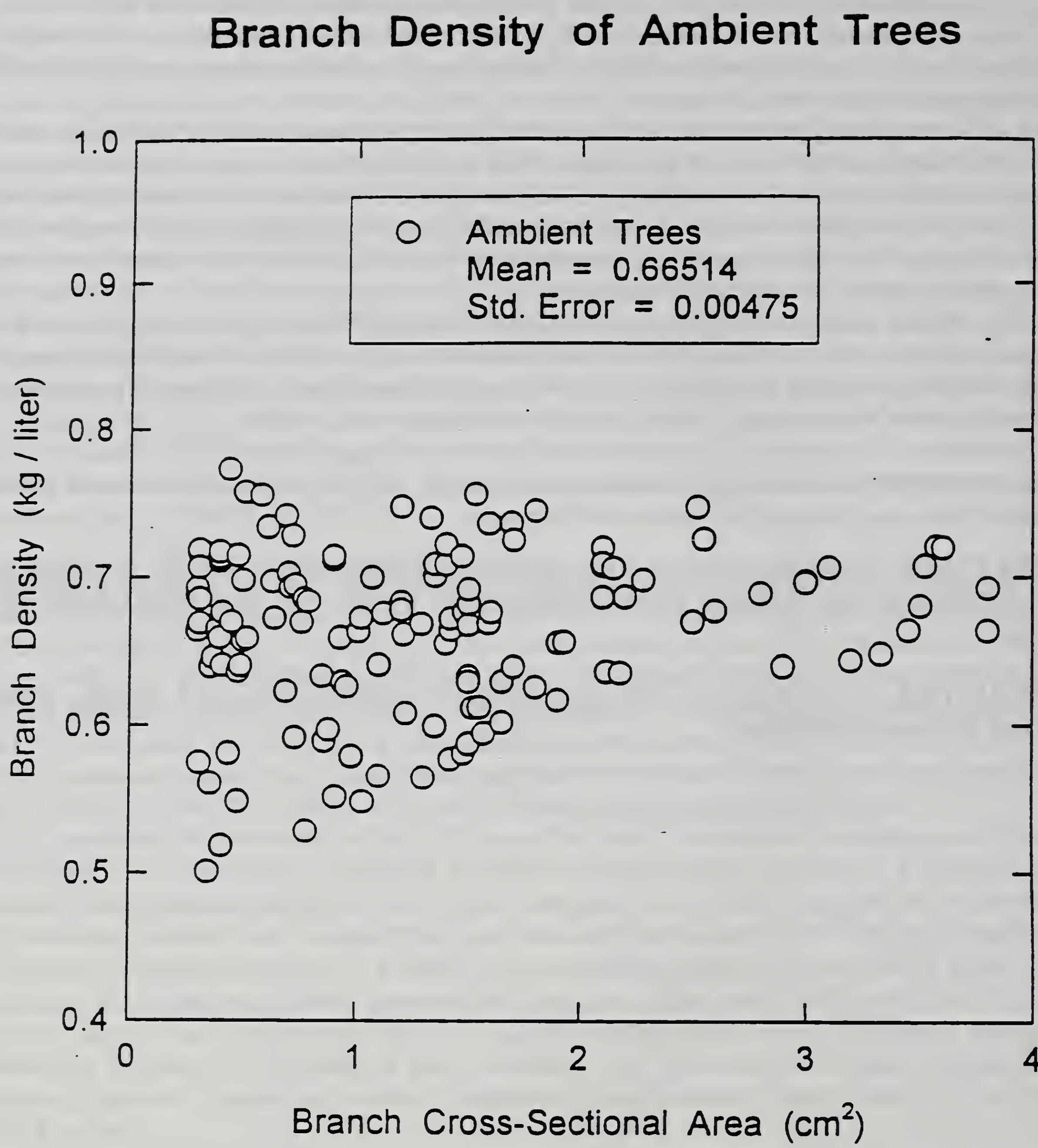


Figure 1. The densities (dry mass/fresh volume) of several 10-cm segments of ambient-treatment (400 ppmv) sour orange tree branches plotted as functions of their cross-sectional areas.

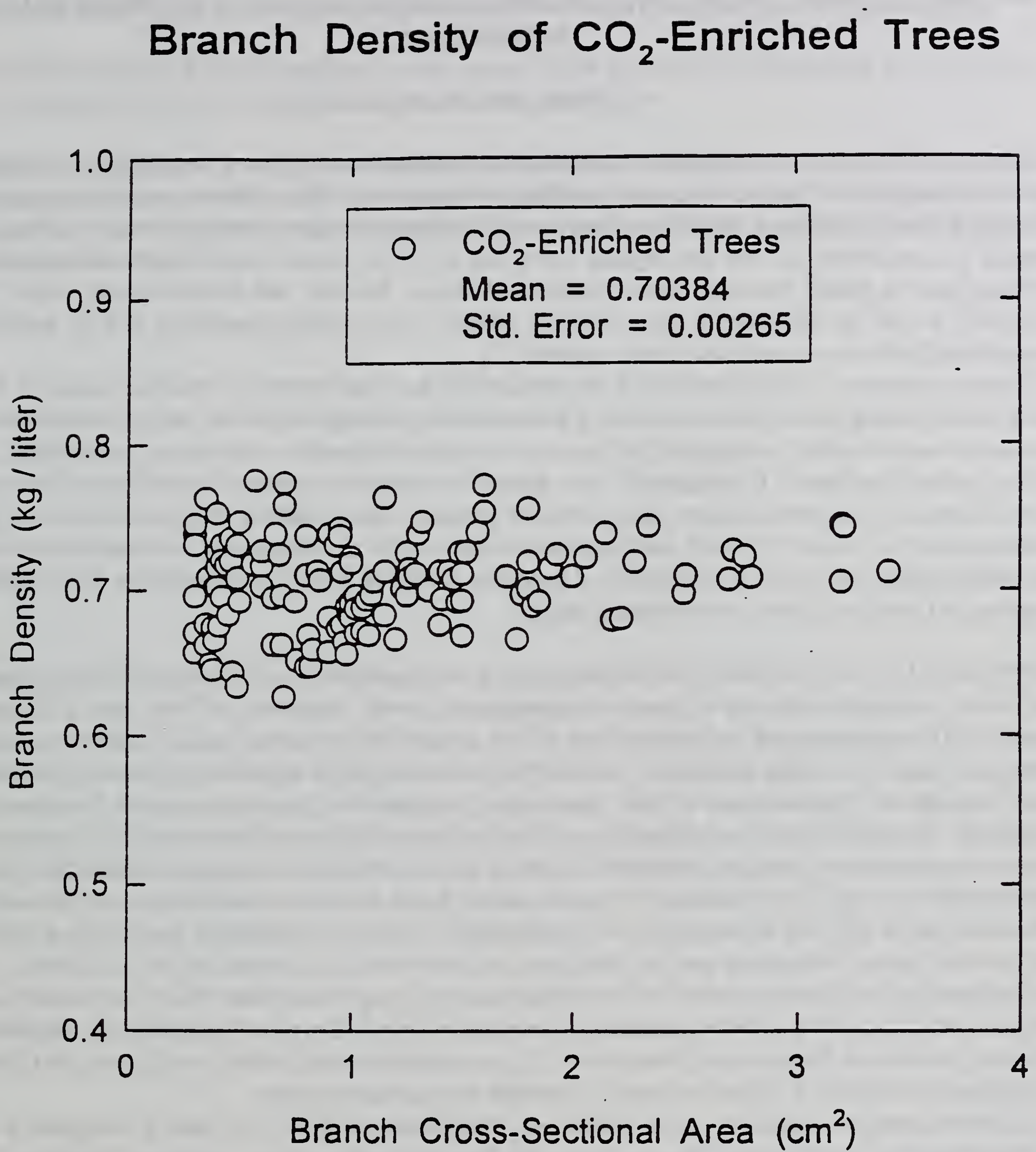


Figure 2. The densities (dry mass/fresh volume) of several 10-cm segments of CO_2-enriched (700 ppmv) sour orange tree branches plotted as functions of their cross-sectional areas.

SIMPLE TECHNIQUES FOR CONDUCTING CO_2 ENRICHMENT AND DEPLETION EXPERIMENTS ON AQUATIC AND TERRESTRIAL PLANTS: THE "POOR MAN'S BIOSPHERE"

S. B. Idso, Research Physicist

PROBLEM: In order to act in the best interests of the biosphere in the face of the rising CO_2 content of the earth's atmosphere, we need to determine the effects of atmospheric CO_2 enrichment on the growth habits of as many different plants as possible, both singly and in combination with competing plants and animals. Also needed is a knowledge of how the ongoing rise in the air's CO_2 content may interact with environmental changes such as global warming, more frequent and intense drought, and intensified soil, water, and air pollution, so we can determine if the deleterious effects of these latter phenomena will be moderated or exacerbated by the concurrent rise in atmospheric CO_2.

So many questions, so little time--this is the problem we face with respect to what the nations of the earth have formally recognized as the most pressing environmental challenge of our day, an issue that requires such a massive research effort to adequately address that it is almost beyond our capacity to successfully respond in the required time frame. Consequently, in an attempt to expand our research capabilities in this important area of science and to interest more young people in pursuing careers therein, this project has as its goal the development of a number of simple and inexpensive experimental techniques that will enable almost anyone to conduct significant research on a variety of questions related to the role of atmospheric CO_2 variability in ongoing and predicted global environmental change.

APPROACH: Over the first three years of the project, a set of guidelines was developed for using inexpensive and readily available materials to construct experimental growth chambers or "Poor Man's Biospheres," wherein CO_2 enrichment and depletion studies of both aquatic and terrestrial plants could be conducted. In their most basic form, these enclosures consist of no more than simple aquariums covered by thin sheets of clear polyethylene that are taped to their upper edges to isolate their internal air spaces from the room or outside air. Several low-cost, low-technology ways of creating a wide range of atmospheric CO_2 concentrations within these enclosures were also developed. Some of the CO_2 enrichment techniques utilize the CO_2 that is continuously evolved by the oxidation of organic matter found in common commercial potting soils, while others rely on the CO_2 that is exhaled by the experimenter. When CO_2 depletion is desired, the growth of the experimental plants themselves can be relied upon to lower the CO_2 contents of the biospheres' internal atmospheres, as can the photosynthetic activity of ancillary algal populations that often occur in watery habitats and that can be induced to grow in terrestrial environments as well. For all of these different situations, a set of simple procedures for measuring biospheric CO_2 is available in a test kit that is sold in tropical fish stores throughout the world and is thus also readily available to practically anyone.

To obtain hands-on experience in the technology transfer aspect of the Poor Man's Biosphere Program, outreach activities were initiated this past year with five eighth-grade biology classes at McKemy Jr. High School in Tempe, Arizona, and with a fifth-grade class at the Salt River Elementary School of the Salt River Pima-Maricopa Indian Community. Students at both schools investigated the effects of atmospheric CO_2 enrichment and depletion on a common terrestrial plant, Devil's Ivy or Golden Pothos (*Scindapsus aureus*), and a common emergent aquatic plant, Yellow Water Weed *Pludwigia peltoides*), under two different light intensities. New sets of students in these same classes will repeat the Pothos experiment during the current school year with some slight variations. Also, two honors biology classes at Tempe High School will conduct a massive twice-replicated study of the growth response of a submerged aquatic macrophyte, Corkscrew Vallisneria (*Vallisneria tortifolia*), to three levels of atmospheric CO_2 (ambient, half-ambient, and twice-ambient) at three different water temperatures and two different light intensities.

FINDINGS: The simple experimental techniques developed in the first three years of the program have been found to work satisfactorily in actual classroom environments at both the elementary and middle school levels.

INTERPRETATION: As the technology transfer aspects of the program are still ongoing and have not yet been fully evaluated, no interpretations of results are reported this year.

FUTURE PLANS: Outreach activities will continue for at least one more year at all three of the currently cooperating schools, after which separate journal articles devoted to teaching the Poor Man's Biosphere Program at the three levels will be prepared. Plans will then be made to bring the program to state and national audiences of science teachers.

QUANTITATIVE REMOTE SENSING APPROACHES FOR MONITORING AND MANAGING AGRICULTURAL AND ENVIRONMENTAL RESOURCES

ARCHIVING MULTIPLE LANDSAT TM AND SPOT HRV IMAGES OF RANGELAND AND AGRICULTURAL REGIONS IN ARIZONA

M.S. Moran and J. Qi, Physical Scientists; W. Ni and R.C. Marsett, Research Specialists

PROBLEM: Over the past 15 years, scientists at USWCL have been conducting large-scale remote sensing experiments at two Arizona field sites: Maricopa Agricultural Center (MAC) and the Upper San Pedro Basin (USPB). This continuing work has resulted in an accumulation of over 130 images from a variety of satellite- and aircraft-based sensors, associated with high-quality ground-based measurements of soil, plant and atmospheric conditions. These images were generally stored on 9-track and 8-mm tapes of varying density and quality, and the ground-based data sets were stored on computers, floppy disks, and 8 mm tapes. Though this extensive data set was ideal for research in long-term change detection, temporal crop and soil studies, and other topics, it was virtually unattainable because there was no central archive on a standard, reliable medium.

APPROACH: An effort was made to compile all the images and supporting data in one location, and transfer these in an orderly fashion to CD. During the archiving process, we found that many 9-track tapes were unreadable, and thus the images were reordered from the vendor. Before transferring the images to CD, a companion "readme" file was created containing information on the acquisition data and location, processing level, file size and format, and any relevant comments about the image or the archiving procedure. Supporting data files were archived with an internal header describing techniques, instrumentation, location, and other relevant information.

A computer database was constructed to provide, among other things, the following metadata for the archive:

DATABASE ATTRIBUTE	ATTRIBUTE DESCRIPTION
Filename	A file naming convention was developed to produce 8-character filenames which are coded for image location, sensor, processing level, and acquisition date.
Project	Many images were acquired in conjunction with on-going ground experiments which provide a rich set of supporting ground-based measurements.
Acquisition Date and Time	This is the date and time of satellite or aircraft overpass supplied by the vendor or recorded by the operator.
Platform and Sensor	The platform (e.g., Landsat5) and sensor (e.g., Thematic Mapper) are recorded with each entry.
Bands	This provides information on the number of spectral bands recorded by the sensor, and in some cases, the spectral band "name" (such as the SAR "C" band).
Vendor Frame	This is the frame designation given by the vendor (e.g., path/row, orbit/frame, K/J). This provides a universally comparable location ID for each image.
Location	This is generally the latitude and longitude of the image provided by the vendor for the centroid or the upper left corner of the image.
View Angle	For pointable sensors, we provide information on the nominal viewing angle of the sensor with respect to the earth's surface.
Weather	This is a simple description of weather conditions taken from the notes of people on site during the overpass, such as "clear", "partly cloudy", "some cirrus", etc.

Media	At this time, the images are stored on media of several types: 8mm tape, 9-track tape, CD, and files on disk (in preparation for writing to CD).
Atmospheric Data	During overpasses of optical sensors, there were often solar radiometers set up to measure atmospheric optical depth for eventual correction of atmospheric effects with a radiative transfer code.
Radiosonde Data	During overpasses of thermal sensors, we often ordered a radiosonde balloon launch at the time of the overpass from the local military base.
Aircraft Data	During many satellite overpasses, we arranged for an associated low-level aircraft overpass to acquire data at the same time with the same spectral bands for validation of satellite-based measurements.
Yoke Data	During almost all satellite and aircraft overpasses, we deployed a yoke-based sensor at ground level to measure surface reflectance and temperature over vegetated and non-vegetated targets.
Processed Subscene	For many images, we extracted a window from the full scene that covered an area associated with our ground-based measurements. We often applied atmospheric and geometric corrections to these windows.
Notes	Notes are included about image archiving status, image acquisition, tape or image condition, etc.

FINDINGS: Example images from the Landsat TM sensor for each field site are illustrated in figure 1, and a progress report on the archiving process is included in table 1. The supporting ground-based data are being compiled and will soon be transferred to CD.

INTERPRETATION: This work will allow long term archiving of and easy access to an exceptional remote sensing data set.

FUTURE PLANS: We plan to continue working on this archive and hope to complete the transfer by Spring 1998.

COOPERATORS: Though many people cooperated in image acquisitions, several have been particularly helpful with this image archiving process: Darrel Williams, NASA Goddard; Tom Mitchell, Hughes Aircraft; Dave Goodrich and John Masterson, USDA-ARS SWRC.

Table 1. A summary of some of the images archived in the USWCL data base.				
Location/ Land Use	Platform/ Sensor	Acquisition Dates	No. of images	Notes
Near Phoenix Arizona/ agricultural, desert and urban	Landsat TM	1985-Present	36 (18 on CD)	•Path/Row = 37,37 •Landsat satellites 4 and 5 •5 pairs of Landsat TM and SPOT HRV XS scenes acquired on the same day
	SPOT HRV Multi-spectral (XS)	1987-Present	34 (28 on CD)	•K,J = 555,284 and 555,283 •SPOT satellites 1,2 and 3 •XS View angles = +28° to -28° •Pan View angles = +23° to -22° •6 pairs of XS (and Pan) scenes acquired on consecutive days at different view angles •1 set of XS scenes acquired on 4 consecutive days at 4 view angles
	SPOT HRV Panchro-matic (Pan)	1987-Present	8 (6 on CD)	
	ERS SAR	1994-Present	6 (0 on CD)	•6 pairs of Landsat TM and ERS SAR scenes acquired within 24 hours
	NASA ASAS	1991	2 days, 2 sites	•2 consecutive days, 29 spectral bands (465-871 nm), at viewing angles +45° to -45°
	Sandia Natl. Labs AMPS	1994-1996	3 (1 on CD)	•High-resolution (1m) TM simulator and Ku-band SAR •3 pairs of AMPS and ERS SAR scenes acquired on the same day
Near Tucson and Sierra Vista Arizona/ rangeland, mountain, riparian	Landsat TM	1990-Present	20 (2 on CD)	•Path/Row = 35,38 •Landsat satellite 5
	SPOT HRV Multi-spectral	1992-Present	5 (5 on CD)	•K,J = 559,286 •View angles = +5° to -29° •1 pair of XS scenes acquired on consecutive days at different view angles
	ERS SAR	1992-Present	12 (4 on CD)	•14 pairs of Landsat TM and ERS SAR scenes acquired within days of each other
	NASA TIMS/ TM simulator	1996, 1997	2 days, multiple sites	•High-resolution (5-15m) 6-band thermal and TM simulator •Images acquired during the dry and wet seasons

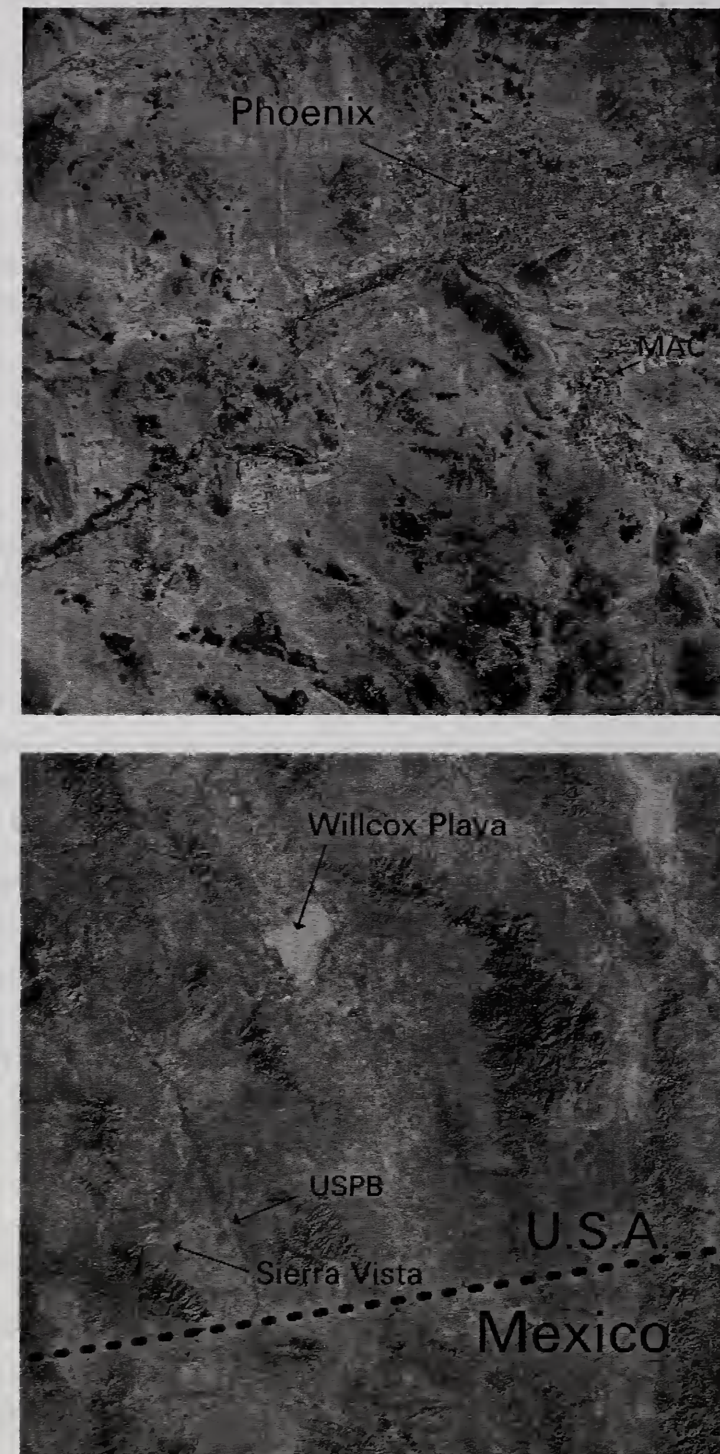


Figure 1. Landsat TM scenes covering two field sites (MAC and USPB) characterized by agricultural (upper image) and wildland (lower image) regions.

REMOTE SENSING TO MONITOR EFFECTS OF PLANT STRESS ON COTTON GROWTH AND YIELD

C.D. Holifield, Physical Science Aid; M.S. Moran and T.R. Clarke, Physical Scientists;
E.M. Barnes and D.J. Hunsaker, Agricultural Engineers

PROBLEM: Plant stress due to field water deficiency is a crucial factor in crop production. Such plant stress can be quantified indirectly by measuring the actual plant evaporation rate and comparing that with the plant potential evaporation. The ratio of actual to potential evaporation (E/E_p) has been used to derive a Water Deficit Index (WDI) which ranges from 0 for no stress to 1 for maximum plant stress, where

$$WDI = 1 - (E/E_p). \tag{1}$$

WDI could be a useful measure of plant stress and a predictor of potential decreases in growth and yield; however, it is difficult to measure E at field scale. On the other hand, there is some evidence that remote sensing techniques may be useful for determining field-scale WDI.

The study was conducted in Upland cotton in central Arizona with the objectives of
(1) examining the effects of stress on cotton growth and yield; and
(2) determining the usefulness of remote sensing measurements for monitoring crop growth and crop stress.

APPROACH: A study was conducted at the Maricopa Agricultural Center near Casa Grande, Arizona (see USWCL Annual Report 1997, Hunsaker et al., High-frequency, small volume surface irrigation). Three irrigation treatments (drip, high frequency, and low frequency) were applied in three replicates of Upland cotton. Measurements were made of plants in the second replicate to monitor crop growth, water stress, spectral reflectance, and temperature.

To monitor plant growth, weekly in situ measurements were made of plant density, height, width, and stem diameter at four locations within each treatment. The plant with the median diameter within each sample site was removed for further laboratory measurements. In the laboratory, the mass (g) of the plant was measured using an analytical balance. Additionally, node, square, flower, and green and mature boll counts were recorded. These parts (with the exception of nodes) were removed and placed in separate paper bags for drying after wet weights were obtained. All leaves were removed and run through a leaf area meter. Leaves and stems were then placed in separate bags for weighing and drying. Samples were dried for 48 hrs at 68 °C, reweighed, and recorded. Results were entered into a spreadsheet designed to compute plant density, fractional plant cover, fractional water content, total biomass, leaf area index (LAI), as well as average plant height, number of nodes, squares, flowers, and green and mature bolls for each treatment. A running average was applied to smooth the weekly data, and a linear interpolation was applied between consecutive measurements to produce daily estimates of plant characteristics.

To monitor plant stress, Dynamax stem flow gages were installed on ten plants within each treatment and transpiration rates were computed at half-hourly and daily rates. The gages were transferred to new plants within the same treatment every two weeks to avoid stem constriction. Whenever a gage was removed from a plant, that plant was harvested and plant LAI was measured. Using the plant transpiration rate, the plant LAI, and the treatment LAI (measurements described in the previous paragraph), it was possible to estimate the treatment evaporation rate (E). We obtained the reference evaporation rate from a local meteorological station located on a cut grass surface, and we used the crop coefficients for Upland cotton to compute the potential evaporation rate (E_p). With this information, it was possible to compute WDI for each irrigation treatment.

To monitor plant canopy reflectance and temperature, radiometers were mounted on a backpack device and carried through the fields to obtain 30 nadir measurements over transects within each treatment. These measurements were made on clear sky days at about two week intervals. The measurements were averaged to produce mean temperatures and reflectances (in blue, green, red and NIR spectral bands) for each treatment on each measurement day.

FINDINGS: Results showed that plants in all treatments had normal growth patterns (Fig. 1). At mid-season, plants in the high-frequency (HF) irrigation treatment had greater vegetative growth (height, biomass, GLAI, and fractional cover) than plants in the low frequency (LF) and drip (D) treatments. The discrepancy decreased toward the end of the season (about DOY 220) and characteristics of all plants in all treatments were similar within Root Mean Squared (RMS) 1σ. The reproductive growth showed a similar trend (Fig. 2). That is, plants in the HF treatment produced a greater number of flowers and green bolls in mid-season, but the number of mature bolls for the HF and D treatments was nearly identical at the end of the season. The plants in the LF treatment produced fewer flowers and had a slightly lower season-end mature boll count than the plants in the other treatments.

These slight differences in vegetative growth and boll formation may be due to the similarly slight differences in plant stress induced by the irrigation treatments (Fig. 3). The differences in WDI for the three treatments was minimal and inconsistent. The only exception was at the end of the season when the plants in the LF treatment exhibited substantial and consistent stress greater than that in the HF and D treatments (after DOY 235). The last flood irrigation occurred on DOY 237 and the DRIP treatment continued until harvest.

The remote measurements of canopy reflectance and temperature were converted to two indices: the Normalized Difference Vegetation Index (NDVI) and the Water Deficit Index (WDI). NDVI is an index sensitive to vegetation density, derived from the red and NIR canopy reflectance (ρ_{red} and ρ_{NIR}), where

$$NDVI = (\rho_{NIR} - \rho_{red}) / (\rho_{NIR} + \rho_{red}). \quad (2)$$

We found strong linear relations between NDVI and plant cover and height, and exponential relations between NDVI and LAI and biomass (Fig. 4).

The WDI was computed from the measurements of canopy reflectance and temperature, and basic meteorologic measurements of air temperature, wind speed, vapor pressure and solar radiation (see USWCL Annual Report 1993, Moran and Clarke, Estimating crop water deficit using the relation between surface-air temperature and spectral vegetation index). The WDI derived from remotely-sensed measurements showed a similar trend to that derived from the stem flow gages with a Root Mean Squared Error (RMSE) of 0.12 (Fig. 5).

INTERPRETATION: Results indicated that there was little stress induced by the different irrigation treatments; and, thus, little difference in plant growth patterns. In general, the plants in the Drip treatment were the shortest and produced the greatest yield. The stunted vegetative growth may have been due to a nitrogen deficiency early in the season. The high yield could be due to the fact that these plants received small, constant amounts of water, resulting in low vegetation (leaves and stems) growth and more energy devoted to reproductive (boll) growth and higher yields.

The HF irrigation treatment produced the largest plants. When cotton receives too much water, vegetative growth can become excessive and less energy is expended in reproductive growth to balance existing vegetative growth. The result is tall "leggy" plants without much reproductive fruit. This could be the reason yield was lower than the other treatments.

The plants in the LF treatment experienced some water stress, especially near the end of the growing season. Periods of stress between infrequent irrigations could have caused more energy use for reproductive growth and could explain why plants in this treatment exceeded the yield of plants in the HF treatment.

Finally, results also revealed that remote sensing could be useful for monitoring crop growth and stress.

FUTURE PLANS: We plan to conduct a follow-up experiment in 1998 with similar instrumentation and an irrigation regime designed to impose specific levels of water stress on each replicate.

COOPERATORS: Bill Dugas, Blackland Research Center, Temple, Texas.

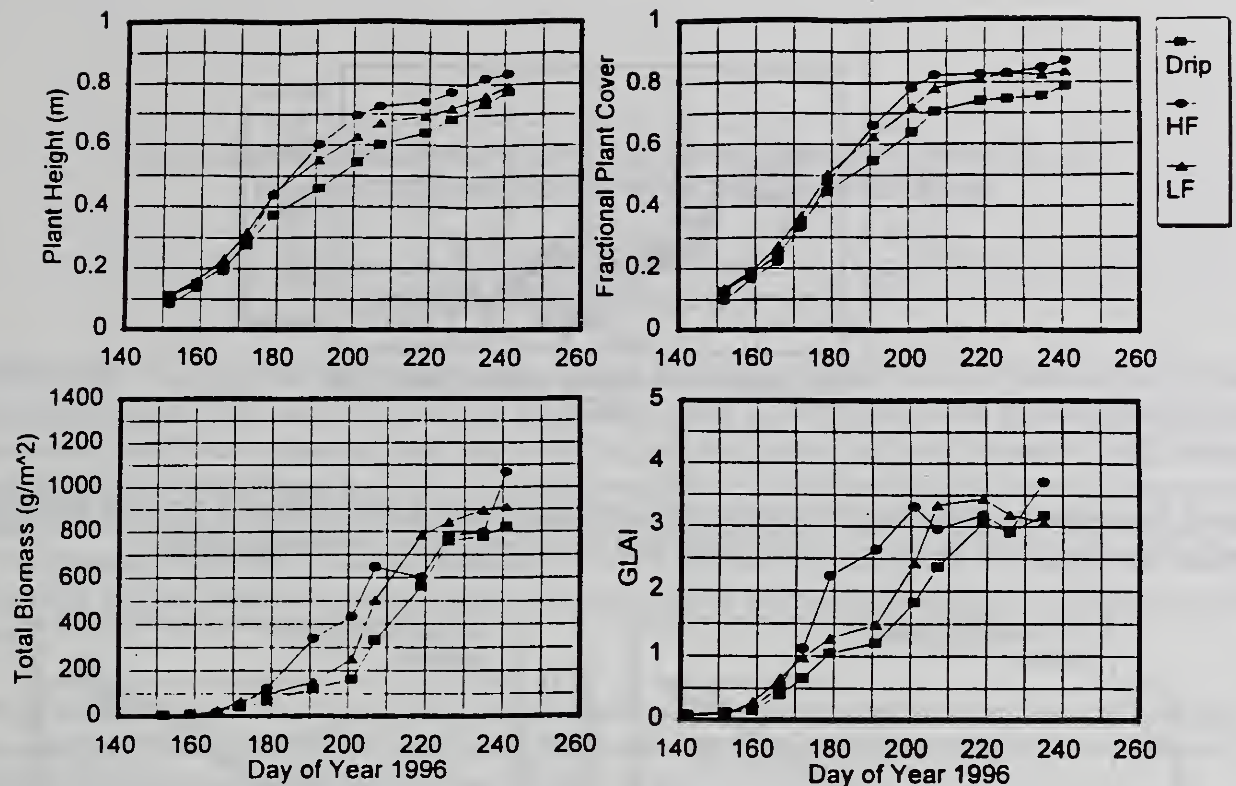


Figure 1. Vegetative growth patterns for Upland cotton with high-frequency, low-frequency and drip irrigation treatments.

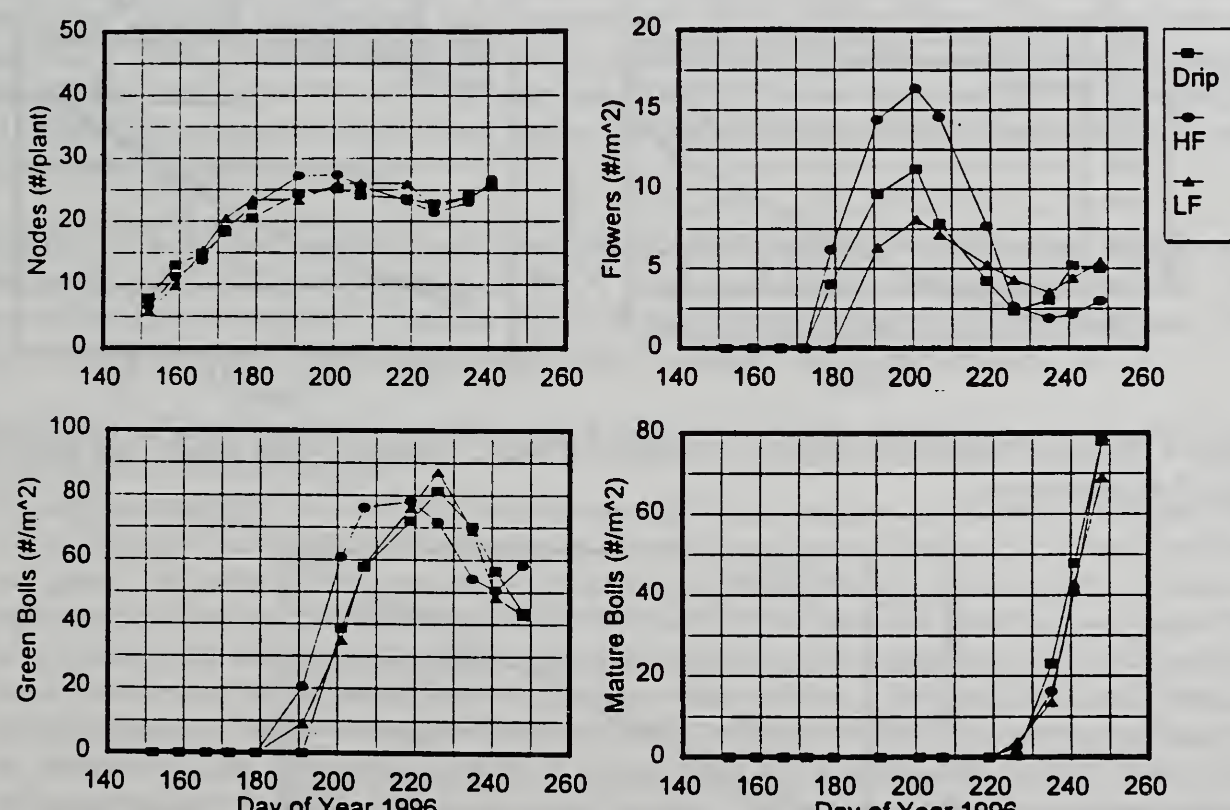


Figure 2. Reproductive growth patterns for Upland cotton with high-frequency, low-frequency and drip irrigation treatments.

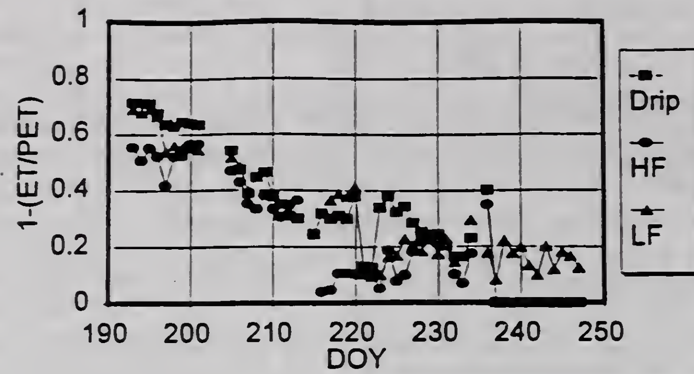


Figure 3. Measurements of daily crop evaporation rates (using stem flow gages) relative to potential evaporation rates for three irrigation treatments. Missing data were due to intermittent instrument failure.

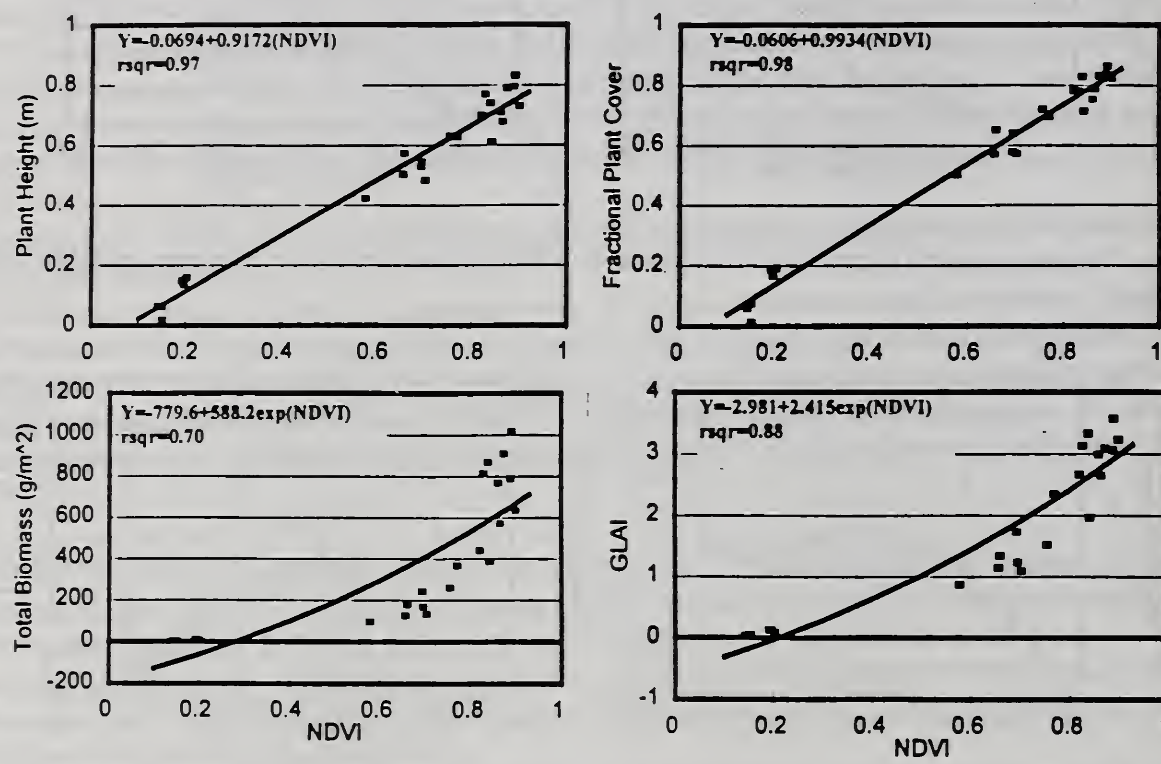


Figure 4. Relations between the spectral Normalized Difference Vegetation Index (NDVI) and plant cover, height, LAI and biomass.

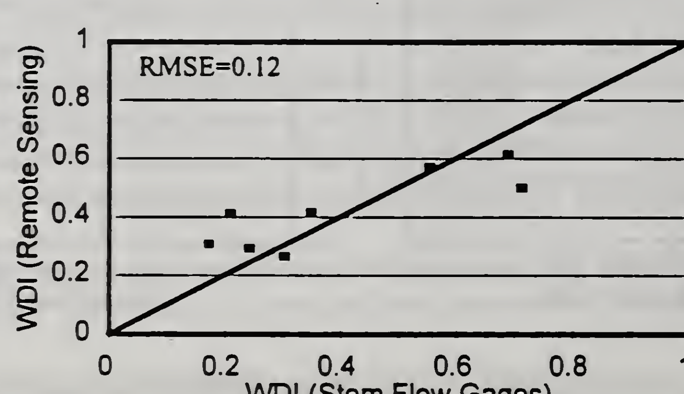


Figure 5. Comparison of WDI measured with in situ stem flow gages and estimated using remotely sensed spectral measurements.

ACCURACY ASSESSMENT OF LAI-2000 INSTRUMENT FOR PLANT PROJECTED AREA AND BIOMASS ESTIMATIONS

J. Qi and M. S. Moran, Physical Scientist; P. J. Pinter, Jr., Research Biologist; and M. Helfert, Biological Science Technician

PROBLEM: The LAI-2000 is a device that can be used to measure the distribution of radiation at a viewing angle range of ±68°. The data acquired with this device would allow the derivation of such plant physical variables as total plant projected area (equivalent to leaf area index) and total biomass. Fairly accurate measurements of total biomass and plant projected areas have been obtained with this device for agricultural areas, where crops are often uniformly distributed in space. The accuracy of this device for grasses, especially for heterogeneous grasses, is less investigated. It is the objective of this study to conduct an accuracy assessment and the limitations of such a device for plant density assessment in naturally heterogeneous grass lands.

APPROACH: Several study sites were selected to measure the plant projected areas using (1) destructive technique and (2) the LAI-2000 device. A total of seven sites in the southeast of Arizona was selected for sampling. These sites and their locations are listed in table 1.

At each site (except at Lewis Spring and Tobosa sites), five plots of size 1x1 meter were randomly selected within the site for both LAI-2000 and destructive sampling. At Lewis Spring and Tobosa sites, seven plots of size 2 x 2 were selected. Both LAI-2000 measurements and destructive samples were made within the plot. However, only destructive samples from 1 x 1 subplots were used to interpolate to the 2x2 plot size and to be related to the LAI-2000 measurements. One "measurement" of LAI-2000 consisted of a reading above the canopy, 5 or 6 readings below the canopy, followed by another reading above the canopy. One must be careful in keeping one's back against the sun to shade the instrument and the area to be measured. The paired LAI-2000 and destructive measurements of plant projected areas and biomass are then compared to examine the accuracy of the LAI-2000 instrument.

FINDINGS: A fairly good correlation was found between plant projected areas determined by destructive technique and by LAI-2000 estimates (Fig. 1). The R^2 is 0.61, with a linear fitting coefficient of 0.57. The scatters of data points along the 1:1 line were most likely due to surface heterogeneity and limited size of the destructive sampling areas. The results should be further examined with a larger data set.

INTERPRETATION: The following are the major factors that contribute to the discrepancies between LAI-2000 and destructive measurements:

- Surface Heterogeneity: The LAI-2000 sensor measures the top of canopy solar radiation and compares the values with the radiation measured underneath the canopy to compute the plant projected areas. As shown in Figure 2, the sensor's views can also be blocked by vegetation stands outside the plots, resulting in higher estimates of plant projected area. On the other hand, if the vegetation density is lower outside the area of interest, the sensor would sense less vegetation, resulting in a lower estimate of the plant projected areas. In either case, the estimated plant projected area is influenced by the adjacent plant density. Because the study areas are spatially heterogeneous, the LAI-2000 estimated values do not correspond closely to the destructive values. One way to avoid this is to place a cap with a narrower field of view, and to point the sensor towards the inside of the plot area of interest. This may result in more accurate estimate. However, the change in the sensor pointing direction may result in unstable measurement of incoming solar radiation due to blocking by the operator, leading to more unstable measurements. The more heterogeneous the area of interest is, the less accurate estimate of plant areas one can obtain with the LAI-2000 instrument. Increases in the number of samples will generally decrease the uncertainties caused by the surface heterogeneity.

- Surface Topography: If the area of interest sits on a hilly topography, the LAI-2000 will tend to overestimate the plant projected area, because of the shadowing effect.
- Sky Condition: If the sky condition is not stable, random errors will be introduced to the data set.
- Other Factors: The LAI-2000 is not able to see residue or portions of the plants that are less than 3/4 or 1" high, because of the sensor's height. This would consistently underestimate the total biomass.

FUTURE PLAN: At the time of this report, the data set was not complete. Therefore, we plan to continue the data collection with both the LAI-2000 instrument and the destructive technique. A detailed analysis will be conducted, and the accuracy of the LAI-2000 for plant projected area measurements will be defined.

COOPERATORS: Phil Heilman, USDA-ARS-Southwest Watershed Research Center, Tucson, Arizona; Amy Stewart, Department of Renewable Natural Resources, University of Arizona, Tucson, Arizona.

Table 1. General description of the study sites, locations, and UTM coordinates.

Sites	UTM (Spheroid Clark 1866, Datum N.A. 27 CONUS, Zone 12)		Primary grasses
	Northing	Easting	
Empire Ranch	3505630	0358076	Mix of native grasses, hilly, owned by Bureau of Land Management
Babocomari Ranch	3499880	0539935	Mix of native grasses, flat, privately owned
Audubon Research Ranch	3496645	0547510	Not grazed, Boer love grass (*eragrostis chloromelas* steud)
Audubon Research Ranch	3496571	0547329	Not grazed, native grasses, some shrubs
Jelks Ranch	3496183	0550522	Some native grasses, some Lehmans lovegrass
Lewis Spring	3491462	0581475	Sacaton grass
Walnut Gulch	3505918	0595070	Tobosa grass

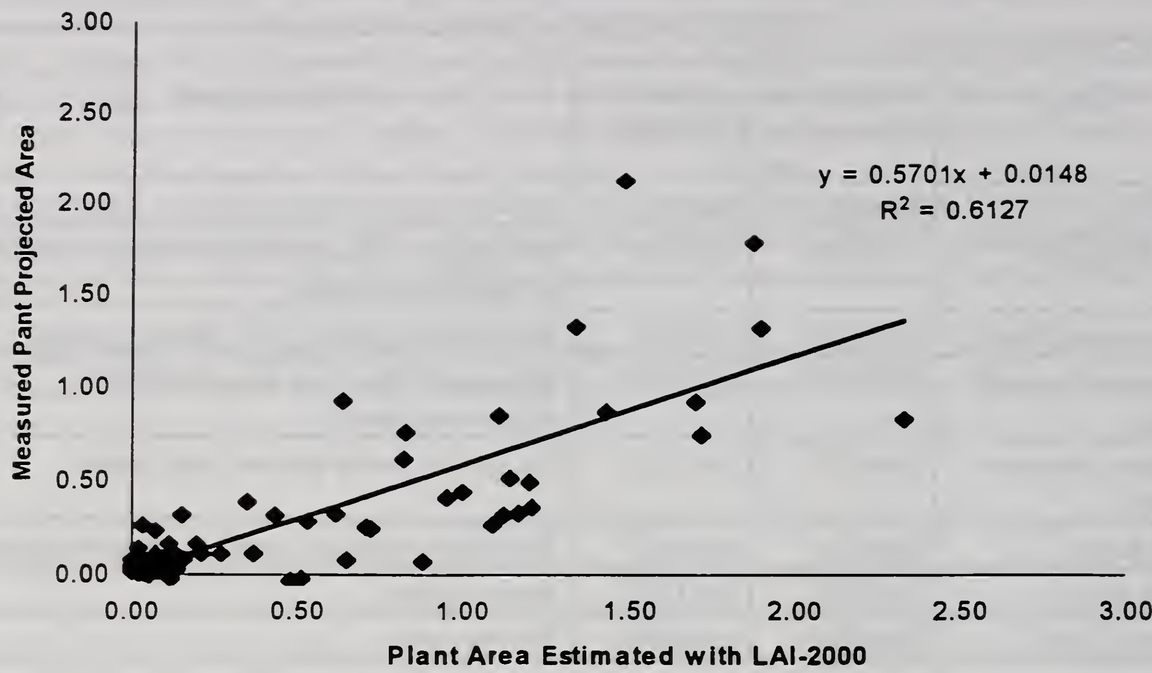


Figure1. Comparison of projected plant areas estimated using LAI-2000 and using destructive techniques.

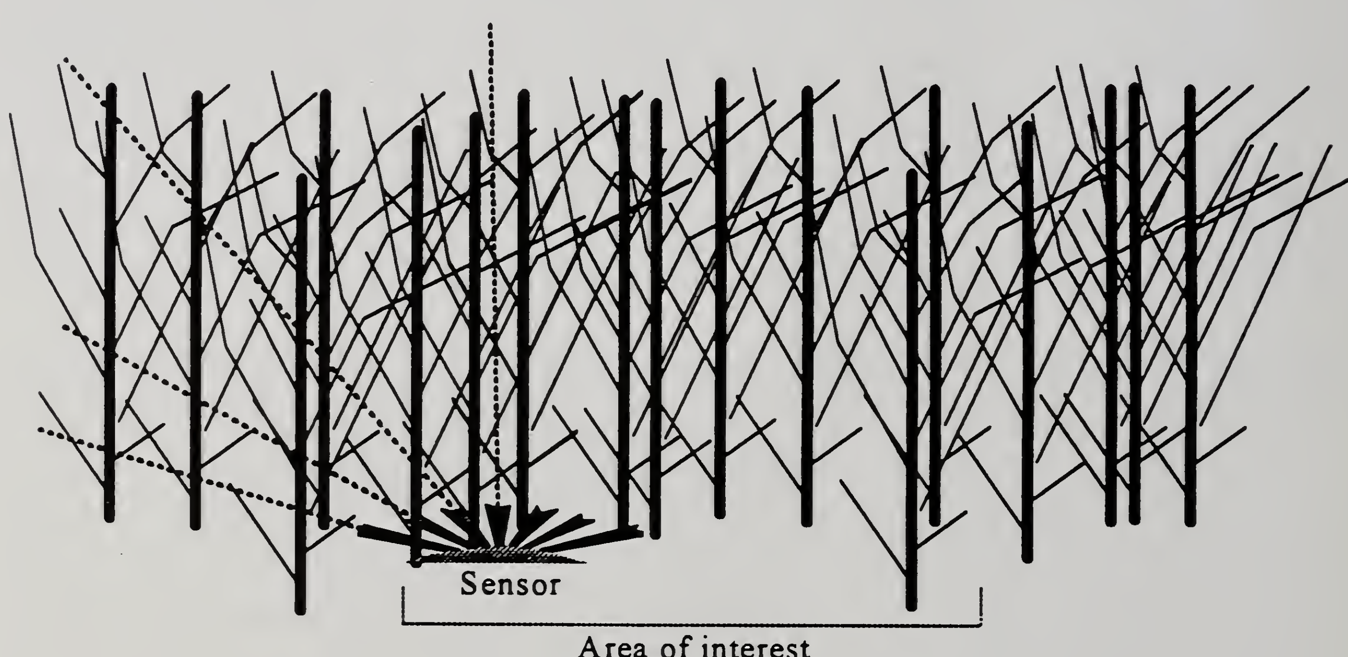


Figure 2. Illustration of measurement condition when using LAI-2000 sensor for estimation of plant projected areas.

MONITORING TEMPORAL SOIL MOISTURE VARIABILITY WITH DEPTH USING CALIBRATED IN SITU SENSORS

D.C. Hymer, Graduate Student; and M.S. Moran, Physical Scientist

PROBLEM: Recent studies have proven that soil moisture plays a critical role in terrestrial land and water processes. In particular, research in semiarid regions has increased the demand for soil moisture data. Unfortunately, long term, spatially distributed soil moisture data sets are rare because conventional soil moisture instrumentation is point based and procedurally intensive. Electrical Resistance Sensors (ERS), however, are capable of collecting hourly data using data-loggers with little maintenance and virtually no supervision. In this experiment, we calibrated a network of ERS sensors in the Walnut Gulch Experimental Watershed to develop a one year, hourly soil moisture data set at 5, 15, and 30 cm depths. This report documents our calibration procedure and future applications of these data.

APPROACH: In 1990, USDA-ARS scientists installed a network of ERS and Time Domain Reflectometer (TDR) sensors in the Walnut Gulch Experimental Watershed (31.72 N°, 110.00° W) located in Southeastern Arizona. Eighteen pairs of ERS and TDR probes were installed horizontally under three bare and three shrub cover surfaces in the Lucky Hills subwatershed at 5, 15, and 30 cm depths. Over a one year period, data loggers recorded hourly ERS values and ARS scientists collected weekly/biweekly TDR readings. ERS readings were stored as a series of raw resistances (ohms) while TDR values were recorded as volumetric water contents (θ_v). ERS and TDR measurements taken at identical times between 1990 and 1991 (August 1990 to December 1991) were extracted for individual trenches and depths. Calibration parameters for each ERS sensor were derived using matched points in the expression:

$$TDR = (a^* (ERS^b)) \quad (1)$$

where: a,b = calibrated parameters, ERS = raw resistance (ohms) and TDR = θ_v (m^3m^{-3})

Statistical tests (t-test) at $\alpha = .05$ and $\alpha = .10$ indicated if the b parameter value was significantly different from zero. This test indicated if the calibration parameters yielded θ_v values that would not represent an average TDR reading. Once acceptable parameters were calculated for each sensor, the calibration expression was applied to the entire ERS data set.

FINDINGS: Statistical tests indicated that 18/18 (100%) ERS sensors had b parameters that were significantly different from zero. Therefore, our calibration expression worked well for each ERS sensor. Figure 1 shows a representative calibration curve with matched TDR and ERS values. Clearly, as resistance values approach zero, the resultant θ_v value increases. Figure 2 reveals, in graphical form, a portion of the resultant data set for one individual trench with sensors at 5, 15, and 30 cm depths.

INTERPRETATION: Our findings indicate that an in situ calibration of ERS sensors worked well because it integrated high frequency ERS data with more accurate TDR data. Ultimately, we were able to compose an hourly, one year data set representing six locations and three different depths. This simple calibration procedure also suggests that the utility of the ERS sensor would make it useful for future soil moisture measurements.

FUTURE PLANS: We plan to use our calibrated data set to validate the Simultaneous Heat and Water (SHAW) Model for use in storm and inter-storm modeling in Walnut Gulch. Additionally, we plan to apply this calibration technique to more recent ERS data sets.

COOPERATORS: Mr. Keefer, USDA-ARS Southwest Watershed Research Center; Mr. Unkrich, USDA-ARS Southwest Watershed Research Center; Dr. Goodrich, USDA-ARS Southwest Watershed Research Center; Dr. Toth, USDA-ARS Southwest Watershed Research Center; Dr. Kustas, USDA-ARS Hydrology Laboratory; Dr. Flerchinger, USDA-ARS Northwest Watershed Research Center.

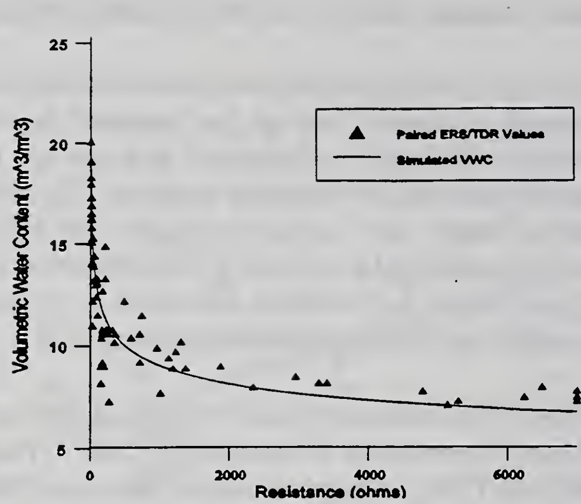


Figure 1. Sample calibration curve for matched TDR and ERS values

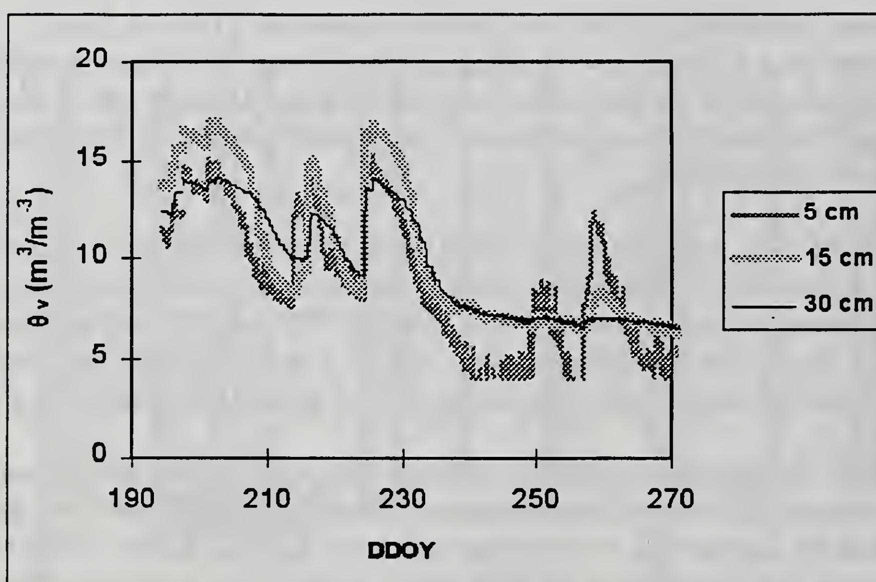


Figure 2. Calibrated θ_v (m^3m^{-3}) values at 5, 15 and 30 cm depths for 1990 (DOY 194-270)

FARM MANAGEMENT DECISIONS USING A REMOTE SENSING AND MODELING APPROACH

PRACTICAL TECHNIQUES FOR CONVERSION OF AIRBORNE IMAGERY TO REFLECTANCES

M.S. Moran, T.R. Clarke, and J. Qi, Physical Scientists;
E.M. Barnes, Agricultural Engineer; and P.J. Pinter Jr., Research Biologist

PROBLEM: Spectral imagery from airborne sensors is useful for monitoring seasonal trends in crop and soil conditions. However, for such applications it is necessary to convert uncorrected digital numbers (*dn*) from sensors to surface reflectance (ρ) to minimize effects of sensor and solar variation. Such conversion has been attempted using ground-based reference targets, on-board up- and down-looking sensors, and in-flight atmospheric measurements. Several approaches are illustrated in figure 1; an analysis of these selected approaches is the topic of the study reported here.

APPROACH: One approach for converting *dn* to ρ is to derive a linear regression equation between *dn* and ρ, based on targets of known ρ within the flight line of the airborne cameras (A1 in Fig. 1). Such targets are often of two types: a portable target of known reflectance that is deployed during the overpass (such as, chemically treated canvas tarps or painted plywood sheets) or an existing target within the scene (often termed a "pseudo-invariant object").

Another accepted approach is to measure atmospheric conditions during the overpass with specialized on-site sensors and then use an atmospheric radiative transfer model (RTM) to convert the aircraft radiance measurements to surface reflectance factors (A2 in Fig. 1).

There are several approaches that are designed to convert *dn* to "apparent" reflectance factor (ρ_a). Apparent reflectance is the ratio of reflected spectral radiation measured by the airborne sensor and the incident spectral radiation measured either at the surface or on-board the aircraft. Such an approach that is gaining acceptance is to mount two instruments on the aircraft, one looking down at the surface and another looking up (180° rotation) with a diffuse lens (A3 in Fig. 1). In that case, ρ_a is simply the ratio of the *dn* measured by the down-looking and up-looking instruments. Another approach is to cross-calibrate two identical sensors, deploying one down-looking sensor in the aircraft and mounting the other down-looking sensor at the field site over a calibrated, high-reflectance $BaSO_4$ panel (A4 in Fig. 1). In that approach, ρ_a can be computed by matching the time of airborne and ground-based data acquisitions, and making a ratio of the airborne *dn* and the ground-based *dn* (which has been corrected with the plate calibration factor).

FINDINGS: Method A1: Chemically-treated reference tarps: Chemically-treated canvas tarps of large dimensions (8 x 8m) are commercially available with stipulations of ρ ranging from 0.02 to 0.80 (to within 0.01 accuracy). We found that tarp non-lambertian properties were substantial for all values of ρ and these properties varied by both the spectral band and the value of ρ (see *USWCL Annual Report 1996*, Moran et al., Calibration of reference reflectance tarps for use with airborne cameras). Furthermore, we found that tarps can be used with some confidence in the visible and NIR spectral range, but measurements in shortwave infrared (SWIR) spectral bands were less predictable.

Method A1: Pseudo-invariant objects: The reflectance factors of four chosen targets within several aircraft-based images were studied to quantify the target reflectance variability over time (Fig. 2). The coefficient of variation ranged from a low of 6% for ρ_{NIR} of the dirt landing strip to a high of 34% for ρ_{NIR} of the roof with E/W-facing pitch. The best target overall was the packed dirt landing strip, but it still had coefficients of variation of 10%, 9%, and 6% for ρ_{Blue}, ρ_{Red} and ρ_{NIR}. The variation in ρ of all targets was significantly correlated with solar zenith angle, but was relatively unaffected by flight altitude, solar azimuth and recent rainfall events.

Methods A2, A3 and A4: There is ample historical evidence that use of atmospheric RTMs for atmospheric image correction (method A2) has proven to be accurate (within ± 0.01 reflectance 1σ) when applied with on-site measurements of atmospheric conditions. Recently, there have been efforts to simplify RTMs to require a minimum number of atmospheric inputs or to derive input from the image itself.

Using method A3, conversion of *dn* to ρ_a is based on side-by-side mounted up-looking and down-looking sensors. It has been reported that this two-sensor method provided imagery with good precision under both clear sky and overcast conditions.

In method A4, two identical sensors are cross-calibrated pre-flight, and deployed separately - one in the aircraft and the other mounted over a calibrated, high-reflectance $BaSO_4$ panel. We matched some video frames (selected for within-frame uniformity) from aircraft-based imagery to Exotech measurements of ρ_a and a relation was derived between image *dn* and ρ_a (Fig. 3). The strong linear relation between *dn* and ρ_a attests to the precision of this approach.

INTERPRETATION:

Method	Advantages	Disadvantages
A1: <u>chemically-treated reference tarps</u>	•Full compensation for atmosphere •No ground operator needed after pre-flight tarp deployment	•Some difficulty in deployment •Tarp maintenance required •Tarp calibration required •Target size should be 8-10 times the pixel resolution
A1: <u>pseudo-invariant targets of known ρ</u>	•Full compensation for atmosphere •No on-site operators nor equipment necessary	•Target ρ must be invariant over time •Target ρ must be known •Non-lambertian properties of the target must be quantified •In this study, accuracy was very low
A2: <u>atmospheric radiative transfer model</u>	•Full compensation for atmosphere •Very accurate •Can be automated	•Requires an on-site, costly solar radiometer for highest accuracy •Requires absolute radiometric calibration of the aircraft-based sensor •Requires some expertise in atmospheric science
A3: <u>two sensors on the aircraft</u>	•Self-contained system on the aircraft •Provides precise value of ρ_a •Good for both clear sky and cloudy conditions	•Requires post-processing to normalize effects of atmospheric attenuation
A4: <u>two sensors at two locations</u>	•Provides a precise value of ρ_a	•Requires instrument cross-calibration •Requires ground-based instrumentation during flight •Requires post-processing to normalize effects of atmosphere •Two sensors in two locations affected by different atmospheric conditions

FUTURE PLANS: We plan to continue identification and assessment of pseudo-invariant objects at MAC and other field sites.

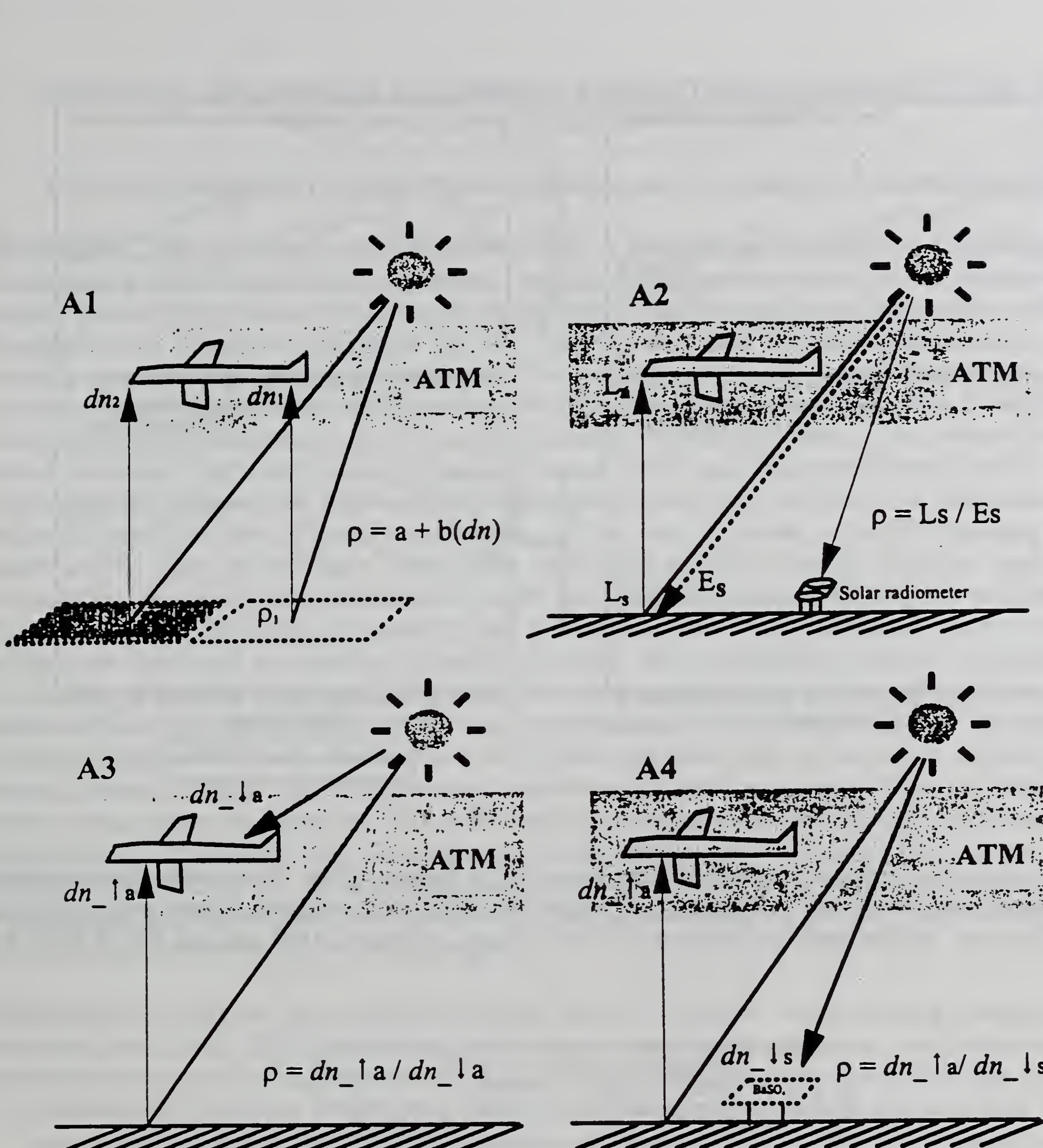


Figure 1. Four methods for retrieving actual and apparent reflectance factors (ρ and ρ_a, respectively) from digital numbers (*dn*) acquired with aircraft imaging systems. This cartoon illustrates the location of the airplane in reference to the atmosphere (ATM), sun and ground surface, and depicts the solar beam as a solid line directed at the detector.

A1: use within-scene targets of known reflectance to compute $\rho = a + b(dn)$;

A2: use a RTM and on-site atmospheric measurements to compute the downwelling and reflected radiances (Es and Ls), where $\rho = Ls/Es$;

A3: use two instruments on the aircraft to measure both up- and down-welling *dn* at aircraft elevation (*dn*_↑a and *dn*_↓a) to compute ρ_a = *dn*_↑a / *dn*_↓a; and

A4: deploy one down-looking sensor in the aircraft and another down-looking sensor on-site over a $BaSO_4$ panel to compute ρ_a = *dn*_↑a / *dn*_↓s.

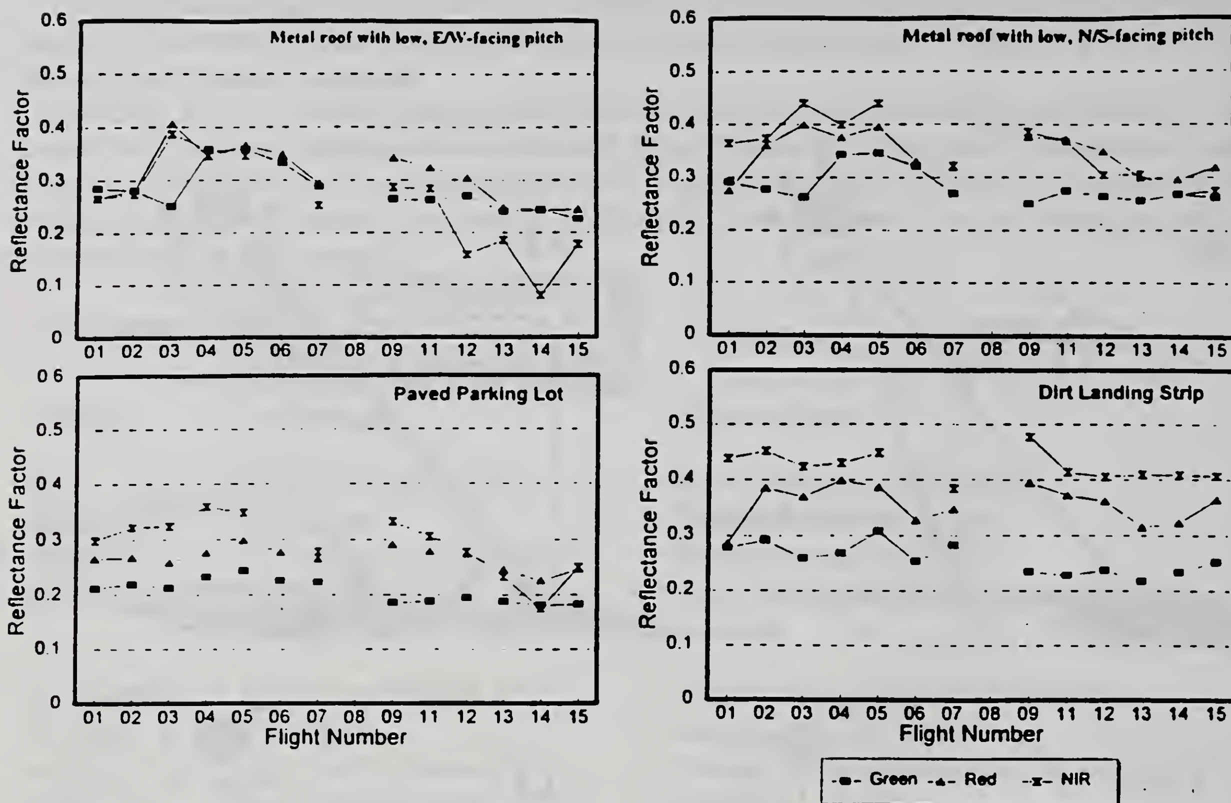


Figure 2. Reflectance factors extracted from video images for 14 flights in 1994. Four pseudo-invariant targets were chosen: a metal roof with E/W facing pitch, a metal roof with N/S facing pitch, a paved parking lot and a dirt landing strip. Spectral bands include green (0.545-0.555 μm), red (0.645-0.655 μm) and NIR (0.840-0.860 μm).

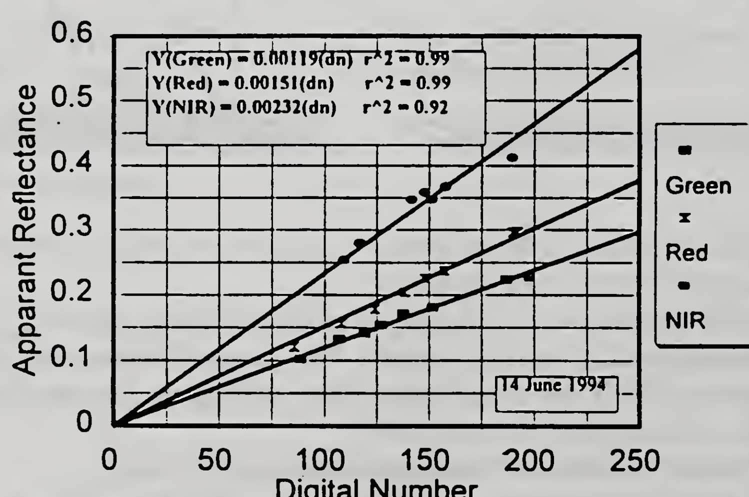


Figure 3. An example of the relation between video image *dn* and Exotech-derived ρ_a values for selected video frames. The strong linear relation between *dn* and ρ_a attests to the precision of approach A4.

PRACTICAL TECHNIQUES TO CORRECT BIDIRECTIONAL EFFECTS FOUND IN AIRBORNE REMOTE SENSING IMAGERY

J. Qi, M. S. Moran, and T. Clarke, Physical Scientists; and P. J. Pinter, Jr., Research Biologist

PROBLEM: Airborne imagery has been proven to be a practical and cost-effective means to acquire remote sensing data for agricultural applications. Its major advantages over space satellite remote sensing imagery are cost effectiveness for small areas, its flexible acquisition schedule and high spatial resolution. Quantitative uses of airborne imagery in the past, however, have been limited because of some generic problems associated with radiometric calibration. One particular problem is related to the effects of the sensor's viewing angles and the position of the sun at the time of image acquisition (Fig. 1 and Fig. 3). Most imaging systems use large field of view (FOV) sensors, in order to obtain a wide swath of areas of interest. As a result, the center pixel of an image has a nadir view angle, while pixels away from the center of the image are acquired with larger viewing angles. Due to view angle differences of these pixels, the brightness, which is related to the reflected radiation off the area of interest, will differ depending on the location of the pixel in the image. Thus, when mosaicking multiple images, significant radiometric discontinuity occurs at joining boundaries of images (see the shaded areas in Fig. 1). This would make it difficult to interpret the images accurately. Many bidirectional reflectance distribution function (BRDF) models were developed to normalize bidirectional effects. They are difficult, however, to be applied operationally to spatially distributed airborne remote sensing images because of the surface heterogeneity, multiple surface types within a single image, and varying vegetation status (temporal growth, for example). Parameters used in models are dependent on the surface properties such as vegetation amount and its spatial distribution. These required parameters (empirical or physical) are usually difficult to obtain with remote sensing means and, therefore, there is no straightforward systematic procedure to use these models for bidirectional effect corrections. Thus their operational applications are limited. The objective of this research is to develop an operational technique to utilize BRDF models for bidirectional effect normalization. This report outlines the procedures, practical considerations, and suggestions for applying such techniques to airborne remote sensing imagery.

APPROACH: To correct the bidirectional effects found in airborne remote sensing images on an operational basis, simple BRDF models are preferred due to their simplicity, easiness, and computing time. To obtain parameters for different types of surfaces, we suggest the following techniques (see Fig. 2):

1. **Classification Technique**: First, assign images into different classes. Second, for each class, extract large number of pixels (from different locations on the image). Third, invert a BRDF model (at one's own choice) to obtain a set of parameters for that model for each class. Finally, use those parameters in the model to calculate the normalization factors to be used for correcting bidirectional effects on images.
2. **Slicing Technique:** Noticing that parameters for most BRDF models vary primarily with the amount of vegetation, we suggest that pixels be grouped according to their vegetation index values (such as normalized difference vegetation index: NDVI). For example, slice the range of NDVI into 0.0 - 0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 groups. For each group, invert a BRDF model to obtain the parameters and therefore creating a look up table(LUT). When applying the normalization factor to images, different parameters are to be used from LUT according to the NDVI values.
3. **Simple Technique:** This technique assumes that all surface types (area of interest) have similar bidirectional properties. Therefore, a single set of parameters can be used. In this case, random pixels should be extracted from multiple images (frames) to be used in the inversion procedure. One needs a large number of extracted pixels in order to obtain a representative set of parameters. Once model parameters are obtained, normalization factors can be easily computed and applied to images. For this

technique, a simple empirical model should perform as well as more sophisticated physically based models. The latter usually require more computing time.

4. **Band Ratioing Technique:** Another technique for BRF correction is to use band ratioing. This technique utilizes the ratio of two different spectral bands in attempting to cancel out the bidirectional effects. This procedure is valid only if the bidirectional effects on both spectral bands are equal and the ultimate effects on the brightness is multiplicative rather than additive; i.e., the resultant brightness $B_\lambda = \varepsilon B_\lambda o$, where ε is a constant accounting for the bidirectional effect and is assumed to be independent of wavelength (λ). In many cases, however, the bidirectional properties of most natural land surfaces are wavelength dependent. Therefore, ratioing two different spectral bands may worsen the bidirectional effects.

FINDINGS: The suggested techniques for correcting bidirectional effects found in airborne remote sensing imagery appear to be effective. An illustration is shown in figure 3, using the suggested simple technique (#3). As can be seen, about 95% of the effect for both red and near-infrared spectral bands was normalized. In comparison, the discontinuity across joining boundary when mosaicking multiple images before the bidirectional corrections is obvious, while after bidirectional correction, the discontinuity almost disappeared.

INTERPRETATION: The results indicate the radiometric discontinuity across joining boundary of multiple airborne images is a major barrier in quantitative applications of these images for agricultural monitoring and change detection. The suggested techniques allow a first order correction of bidirectional effects, increasing the confidence when using these images for quantitative purposes. These techniques not only reduce the bidirectional effects, but also allow inter-comparison of multiple data sets acquired with different sensing systems of varying viewing configuration. These techniques can be used on an operational basis, but care should be taken in the use of model parameters. It should be pointed out that, since most BRDF models are developed in reflectance domain, digital numbers extracted from airborne images should be converted to reflectances if possible. If not, we suggest that the digital numbers be normalized by a factor (e.g. 255) so that the resultant pixel values are within the range of 0 and 1.

FUTURE PLANS: We plan to thoroughly test and validate these suggested techniques with airborne images from different sensing systems. A detailed documentation is planned to be made concerning the use of BRDF models for practical corrections of bidirectional effects. We intend to complete a Unix based program that allows operational applications of varying BRDF models for bidirectional correction purposes.

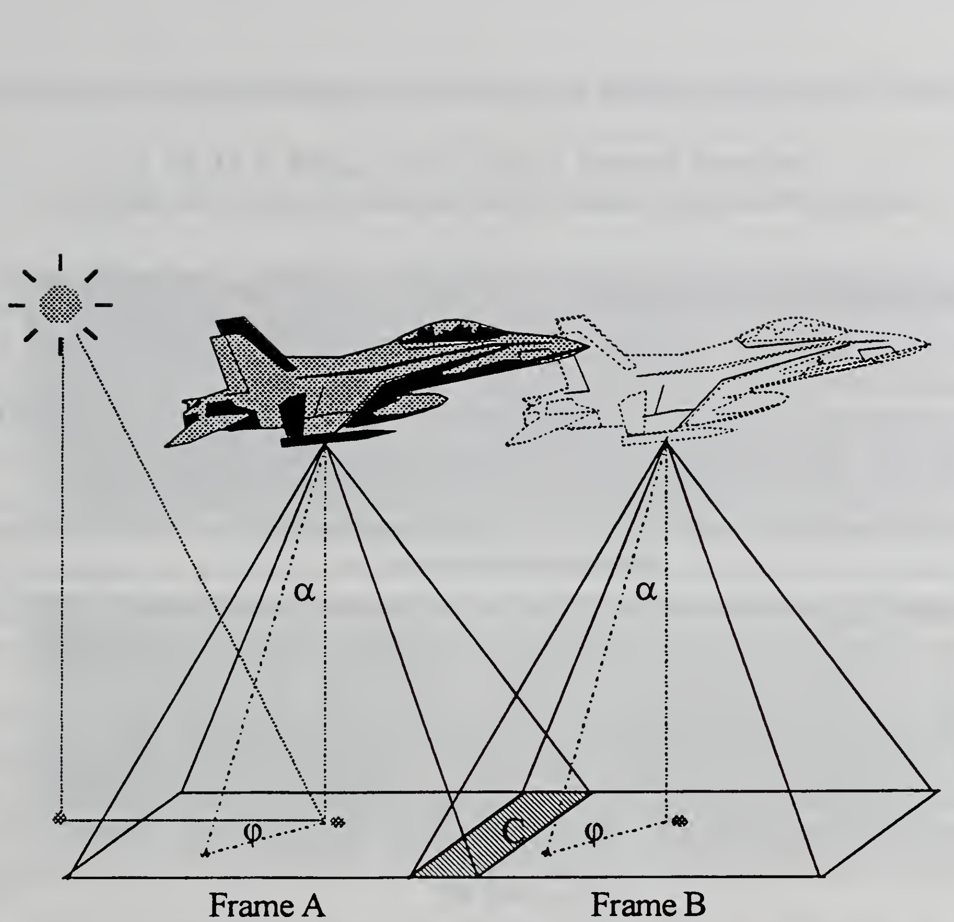


Figure 1. Graphical presention of airborne image acquisition systems

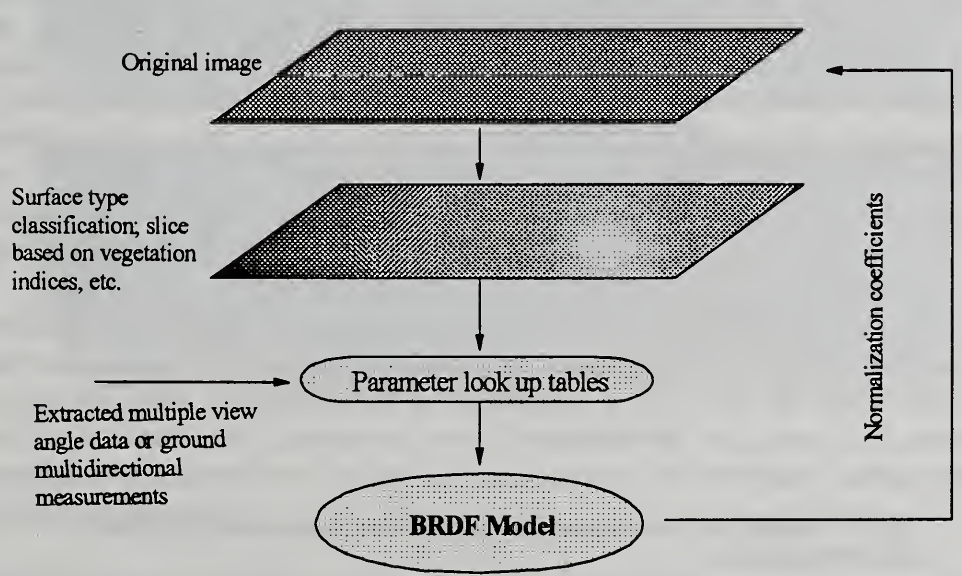


Figure 2. An outline of techniques that can be used to normalize bidirectional effects found in airborne remote sensing images

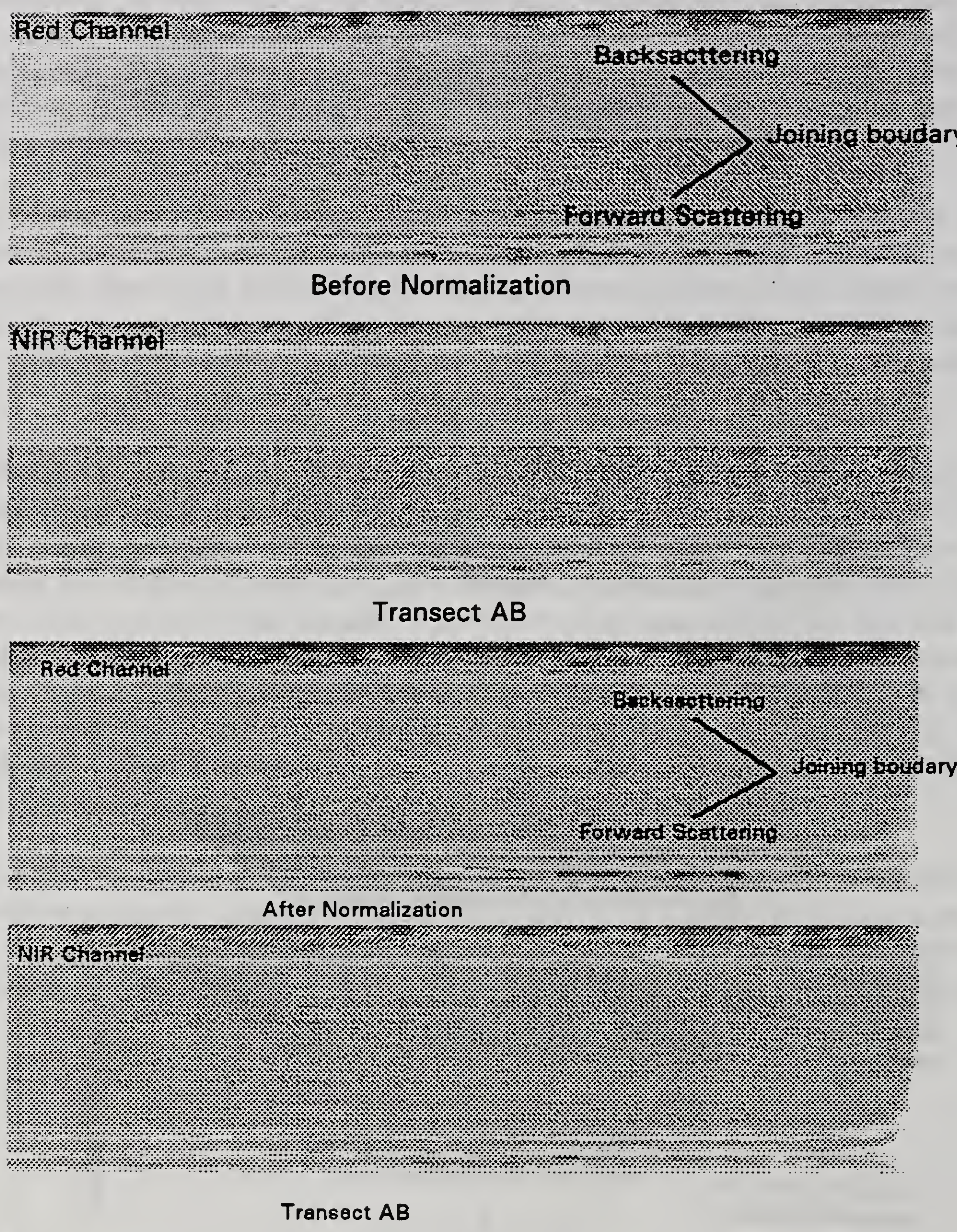


Figure 3. Comparison of two mosaicked images before and after normalization of bidirectional effects.

VALIDATION OF A BRDF MODEL USING DATA FROM AGRICULTURAL AREAS

J. Qi, M. S. Moran, and T. Clarke, Physical Scientists;
P. J. Pinter Jr., Research Biologist; and E. Barnes, Agricultural Engineer

PROBLEM: Many Bidirectional Reflectance Distribution Function (BRDF) models have been developed to characterize the bidirectional properties of terrestrial surfaces. Most discrepancies between model-predicted values and measured values occur around the hot spot location, where the sensor's view direction is in the same direction as the illumination source. Recently, Dymond and Qi (1997) developed a simple model based on radiative transfer theories. In this model, the authors included a hot spot term as a function of solar zenith angle. This model was developed for visible spectral bands, and was validated using data for grassland and pine forest. As such, the performance of this model in the near-infrared spectral region was unknown. Furthermore, it was not tested with data from agricultural areas. Therefore, the objectives of this research are to investigate the suitability of this model for near-infrared spectral band, and to validate this model with data from such agricultural fields as bare soils, oats, wheat, and some artificial surfaces such as tarps of known reflectances.

APPROACH: Bidirectional reflectance factors were measured over five types of agricultural fields: bare soil, oats, cotton, wheat, and two artificial tarps of known reflectances. These data sets were used to invert the model and predict the reflectances. The performance of this model was compared with theoretical (Verstraete et al., 1990) and empirical BRDF models (Shibayama, 1985). The reflectance values simulated with Dymond-Qi model were compared with field measurements and simulated values with other models.

FINDINGS: As stated in the original work of Dymond and Qi, the model was developed for visible spectral regions. The simulated results (Fig. 1) proved that the model performed well for visible spectral bands with agricultural data sets, but failed for the near infrared band (not shown in Fig. 1). However, when unrestricted parameter boundaries were used (in this case, the parameters no longer have their original physical meanings), the model performed as well as either the physically-based Verstraete and Pinty (VP) model, or the empirical Shibayama model. Although it was originally developed for grass and pine forest, the model predicted very well the bidirectional properties of agricultural crops, bare soil, and two artificial surfaces (Fig. 1 and 2). The simulated reflectances are very close to the measurements with R^2 of 0.99. The R^2 values of other models for different spectral bands are listed in table 1 and their graphical comparisons are presented in figures 1 and 2 for each surface type. Overall, the model performed well when compared with the other two models.

INTERPRETATION: The simple Dymond and Qi (DMQI) model applies well to agricultural fields as well as other surfaces. Because of its simplicity and its capability to handle hot-spot function properly, this model appears more attractive for applications in agricultural areas. Since the model only employs three parameters, it is easy to use on an operational basis. Because of the inclusion of an improved hot-spot function in the model, it is expected that this model would perform well for many surface types, making it easier for agricultural applications.

FUTURE PLANS: We plan to test this model with a wide range of bidirectional data sets, especially with data acquired at large viewing angles (180°).

COOPERATORS: Christophe Miesch, ONERA-CERT DERO, Toulouse, France; John Dymond, Landcare Research - Manaaki Whenua, New Zealand.

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Verstraete, M. M., Pinty, B. and Dickinson, R. E. (1990), A physical model of the bidirectional reflectance of vegetation canopies, 1: Theory, J. Geophys. Res. 95:11755-11765.

Table 1. Statistical results of linear regression using different BRDF models

Models	Blue	Green	Red	NIR
SHW	0.9993	0.9986	0.9982	0.9925
DMQI	0.9993	0.9986	0.9980	0.9791
VP	0.9992	0.9987	0.9978	0.9924

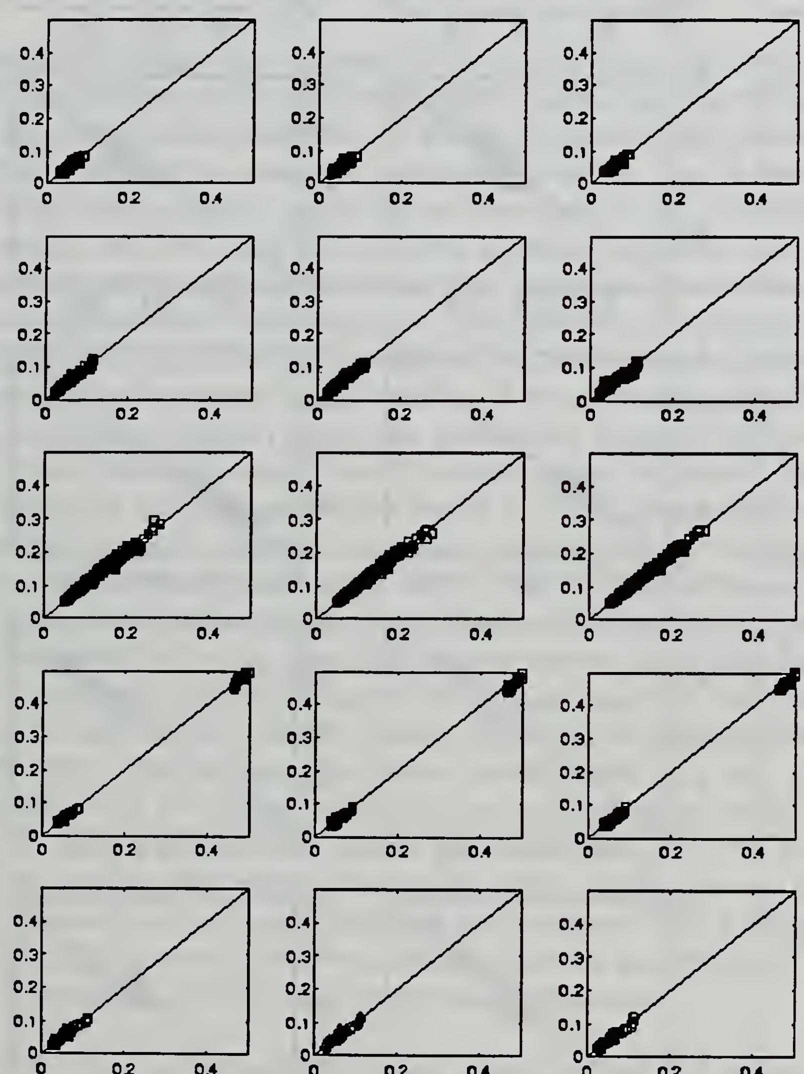

Figure 1. Comparison of Dymond and Qi model (Center) with Shibayama (Left), and Verstraete and Pinty (right) models using data acquired over Cotton (row 1), Oats (row 2), Soil (row 3), Tarps (row 4), and Wheat (row 5). The vertical axis is simulated values while the horizontal axis is measured values of reflectances in the visible spectral regions.

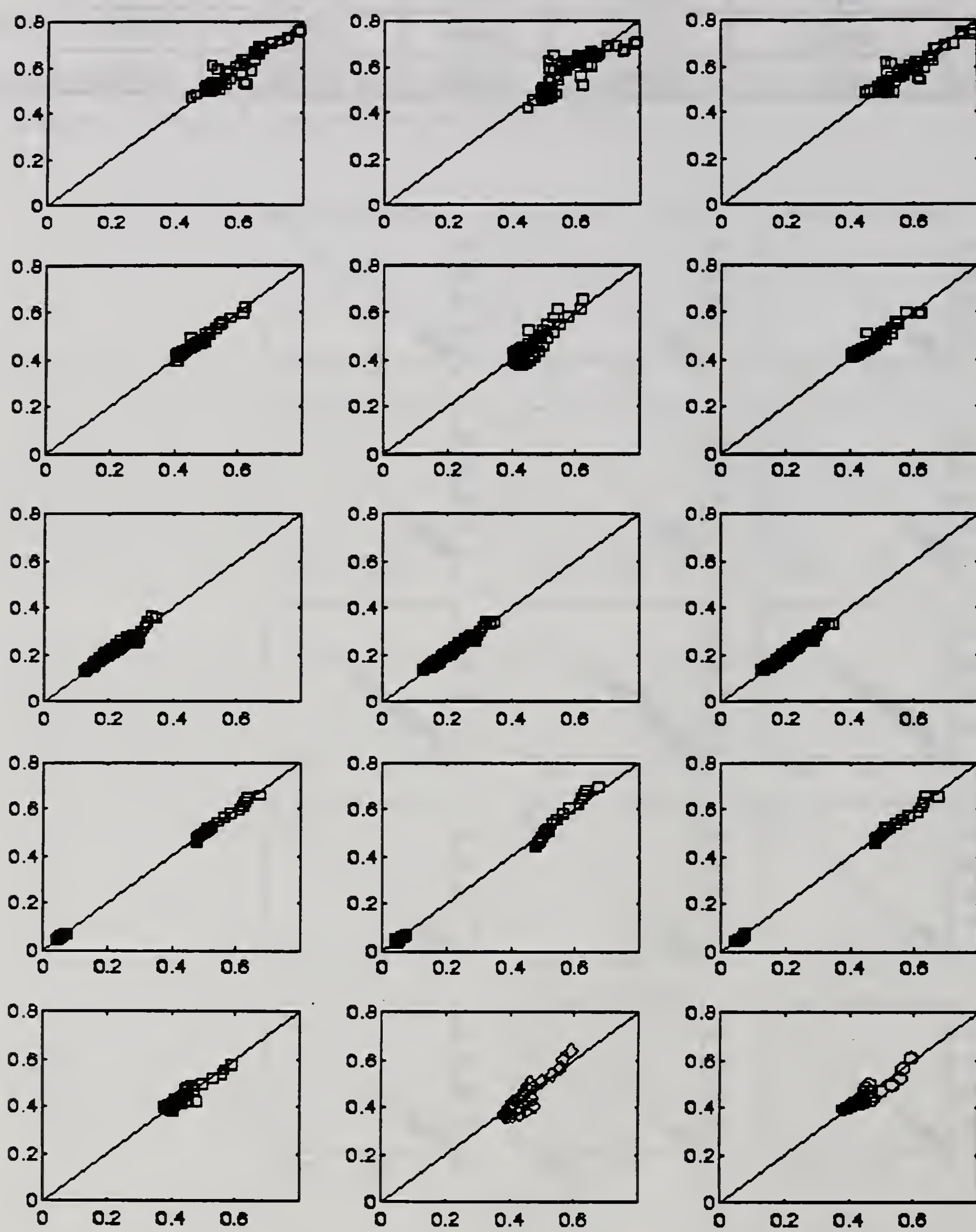

Figure 2. Comparison of simulated versus measured values of near-infrared reflectances with the three models: Shibayama (Left), Dymond and Qi (Center), and Verstraete and Pinty (Right). The vertical axis is simulated while the horizontal axis is measured values of reflectances.

INTEGRATION OF REMOTE SENSING AND GROWTH MODELS TO ASSIST IN PRECISION CROP MANAGEMENT

E.M. Barnes, Agricultural Engineer; J. Qi, Physical Scientist; and P.J. Pinter, Jr., Research Biologist

PROBLEM: The development of crop models has been progressing since the 1970s, but they have been designed to simulate average field conditions; however, more recently tools have been developed to integrate growth models with geographic information systems (GIS) at either regional, field or plant row scales. The objective of this study is to determine how remotely sensed observations can be used to improve a model's ability to simulate actual field scale variability.

APPROACH: Wheat was selected as the first crop to test methods to integrate remotely sensed observations with crop models due to the extensive growth and remote sensing data set collected during the FACE wheat experiments (Kimball et al., 1995). Two modeling approaches are currently being evaluated. In the first approach, it is assumed that methods are in place to obtain remotely sensed estimates of physical plant characteristics, specifically leaf area index (LAI). CERES-Wheat (Ritchie and Otter, 1985) was selected as the crop model to use in this approach because it is a process oriented model capable of simulating different management practices, while maintaining reasonable input requirements that would not prevent its application by a farm manager. CERES-Wheat was modified to accept LAI as an input, so that the model's predictions of LAI can be forced to match observations at selected times during the season. The modifications have been tested using 3 seasons of data collected during the FACE experiments. During the 1995-96 experiment, Datron/Transco Inc. provided an image of the field in the blue, red, green and NIR portion of the spectrum using aircraft mounted digital cameras. The image spatial resolution was approximately 2m and was acquired on March 31, 1995, approximately 10 days after maximum canopy cover had been reached. The data was used to generate a Ratio Vegetation Index (RVI, the ratio of near infrared to red reflectance) map of the field. Supervised classification of the image was used to group different areas of the field into LAI ranges. The training data for the classification procedure was obtained by using measured LAI of the plots sampled near the time of the over flight. Yield predictions were made for the various LAI classes obtained in the images using the modified CERES model. In the second approach, the AFRWHEAT model (Porter, 1994) was combined with the Sail Radiative Transfer model (Verhoef, 1981). Output from the wheat growth model was used to predict the spectral reflectance signature that would be seen by a satellite if the crop were at the model's simulated stage of development. This allows a direct comparison between the satellite data and crop model predictions. Any deviations between the satellite observations and crop model's predictions can then be used to adjust the wheat model's parameters so that actual conditions are simulated. This approach was also evaluated using data collected during the wheat FACE experiments. Cultivar parameters for the model were determined using the first two season's of FACE data for the control treatments.

FINDINGS: For the first approach using CERES-Wheat, it was determined that observations of LAI alone were not sufficient to improve the model's yield predictions if the timing of the crop's growth stages was not properly predicted. In an attempt to compensate for this limitation, a routine was added to the model to allow the user to specify when the transition between two growth stages occurs. Currently, it is uncertain if all of the crop growth stages can be estimated from multispectral data; however, limits can be placed on three stages as illustrated in figure 1. The figure is a graph of the RVI obtained from a hand-held radiometer and leaf area index versus time. By examining the RVI time series, limits can be placed on when emergence (point A, RVI begins to increase), end of leaf development (point B, maximum RVI reached) and maturity (point C, late season minimum RVI) occurs. When the growth stages are properly predicted, the data sets evaluated in this study indicate that the model's prediction of final grain yield showed a greater sensitivity to changes in LAI during the end of the season than during canopy

development. Figure 2a is the RVI image of the FACE field, while figure 2b is the LAI map of the field determined by supervised classifications. In table 1, the yield predictions associated with the LAI classes of figure 2b are shown. The use of one LAI observation and no adjustment to the growth stage did allow the model to predict the range in observed yields to within 8%. However, the image was taken at an optimal time period, during the time of grain filling, when the model predictions of yield appear to be most sensitive to changes in LAI. Such predictions are useful to generate a predicted yield map, but this does not provide the information needed earlier in the season when it is possible to change management practices. Initial results with the ARCWHEAT model show that it is capable of predicting the maximum LAI and final yield data for the different water-stress, nitrogen and CO_2 conditions; however, the temporal trends in LAI did not closely match observations for the first year of the FACE wheat experiments.

INTERPRETATION: Dependable methods to forecast of the impact of variability in the crop canopy during the early season on yield would provide a new tool for producers to make informed decisions in the application of precision farming practices. The approaches taken in this study demonstrate that the integration of remotely sensed data and crop models can lead to such a tool; however, improvements in the current methods are needed.

FUTURE PLANS: Future work will focus on the application of iterative techniques to adjust CERES-Wheat's predictions to match observed LAI. It is hoped that by using an iterative procedure to adjust key growth parameters, observations early in the season will have a greater impact on predicted yields. Consideration will also be given to integrating remotely sensed estimates of evapotranspiration (ET) with the model. Through the combination of LAI and ET observations, it may be possible to determine if any departure in the model from observed conditions is related to its growth or soil parameters. Investigations will also be conducted to determine if fuzzy-c classification techniques can be used with the reflectance data to classify additional wheat growth stages. The next step in the application of the Afrcwheat2 model will consist of using the radiometric data (ground and satellite) to constrain the vegetation model. This will be accomplished by assuming that the correction of the model's initial state is obtained by minimizing the difference between the observed and simulated temporal profiles for adjusting the model's initial conditions.

COOPERATORS: Sophie Moulin, Centre d'Etudes Spatiales de la BIOsphère (CESBIO/CNES/CNRS/UPS), Toulouse Cedex, France; Gary Knauck and Kevin Spry, Datron/Transco Inc.; David Jones, Visiting Agricultural Engineer.

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Table 1. Predicted and observed* wheat yields corresponding to the LAI classes of Figure 3(b).

LAI Class of Figure 3b.	Yield (kg/ha) Observed	Predicted	Percent Difference
> 5.0	8000	7454	6.8
4.5 to 5.0	7500	7417	1.1
4.0 to 4.5	7000	7366	5.2
3.0 to 4.0	6500	7008	7.8
2.0 to 3.0	5700	6045	6.0

* Observed is the approximate yield determined for the various treatments during the 1995-96 experiment and have been assigned to an LAI class based on the LAI of that treatment during the time the image was acquired.

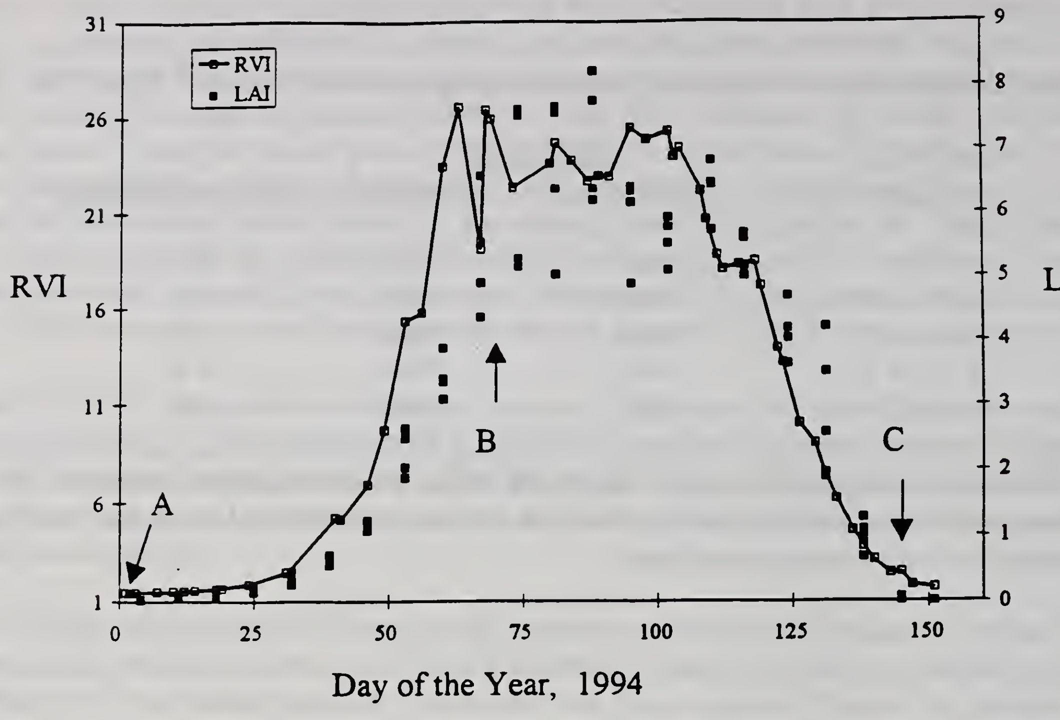
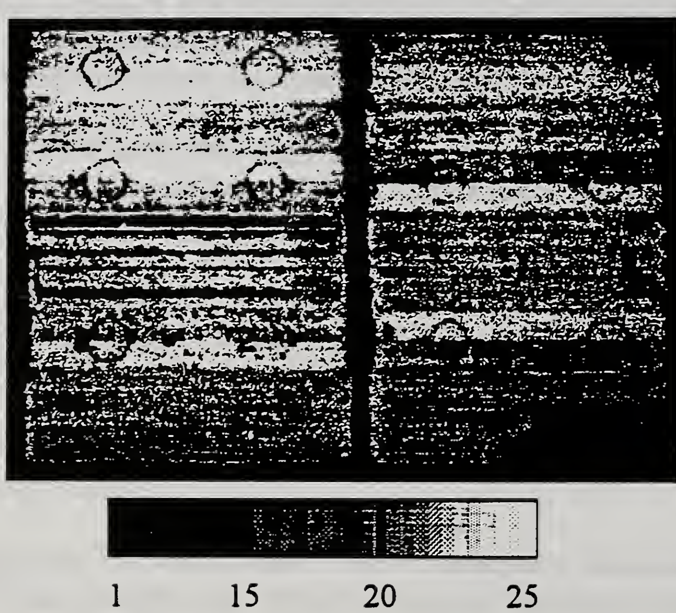
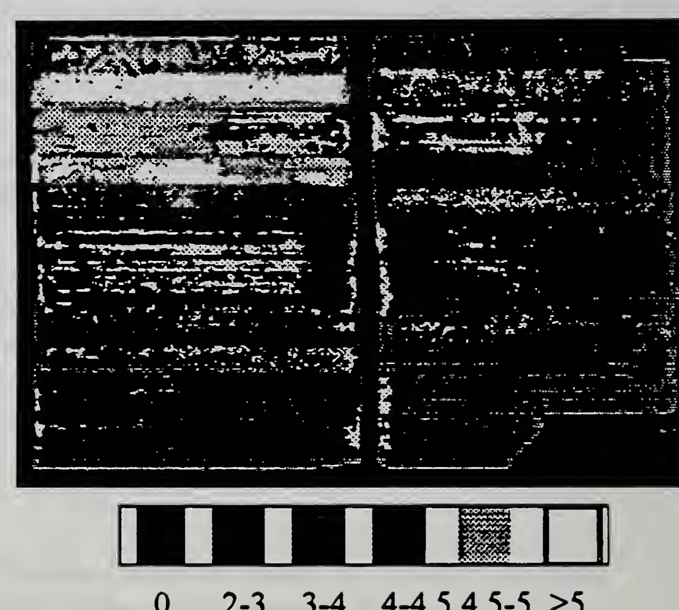


Figure 1. RVI and LAI versus time for the wet treatment of the 1993-94 growing season. A indicates the approximate time of emergence, B end of leaf development, and C shows crop maturity.



(a) RVI Map



(b) LAI classification map.

Figure 2. Maps derived from the March 31, 1996, image data (a) RVI and (b) LAI classification.

PROGRESS ON MADMAC IMAGE PROCESSING AND ANALYSIS

E.M. Barnes, Agricultural Engineer; M.S. Moran, Physical Scientist; M.G. Baker, Research Specialist; T.R. Clarke, Physical Scientist; J. Qi, Physical Scientist; and P.J. Pinter, Jr., Research Biologist

PROBLEM: Interest in precision farming (PF) practices (managing agricultural inputs to meet exact crop requirements within the field) has increased in the last five years as variable application equipment and yield monitors have become commercially available. One limitation to the cost effectiveness of PF is the intensive labor and laboratory analysis associated with the large number of crop and soil samples required to make management decisions over small areas. Remote sensing techniques have the potential to reduce PF sampling demands (Moran, et al., 1997); however, there are a limited number of remotely sensed data sets spanning a complete crop growing season to demonstrate the application of remote sensing techniques to PF. Interest in such data has increased with the recent plans of several companies to launch civilian satellites, with the agricultural industry cited as a potential customer (Fritz, 1996).

APPROACH: The data collected during the Multispectral Airborne Demonstration over the Maricopa Agricultural Center (MADMAC) in 1994 is being used to investigate possible applications of remotely sensed data to precision farming. Radiometric and band-to-band registration has been completed for all of the single image frames. Geometric registration of the single frames has been completed for the first 8 of the 14 flight dates and registration of the remaining flights is in progress. Ground-based observations (e.g., crop type, height, percent cover; soil conditions; and notes on anomalies such as weeds or insect damage) have been integrated into a geographic information system (GIS) and linked to field locations. For a limited number of frames, remotely sensed products such as evapotranspiration and leaf area index have been created. Recently data from over 500 soil sampling locations across the farm collected by Post et al. (1988) has been integrated into the GIS database.

FINDINGS: The application of remotely sensed data to precision farming problems typically will involve correlating the spectral data to some physical parameter. The quantitative application of remotely sensed data requires careful radiometric and bidirectional correction. The MADMAC data set has been used to develop various correction methods and potential agricultural applications of remotely sensed data (Moran et al., 1996; see USWCL Annual Report 1997, Moran et al., Practical Techniques for Conversion of Airborne Imagery to Reflectances). Additionally, current automated geometric registration techniques are not sufficient for most precision farming applications and manual registration appears the only alternative at the present time. The ability of multispectral data to provide maps of crop density and evapotranspiration (ET) has also been demonstrated (Clarke et al., 1995; Barnes, et al., 1996). Remotely sensed estimates of crop density can be used to aid in the definition of within field management zones (e.g., Yang and Anderson, 1996), and estimates of ET can be used in determining precision application of irrigation water. Initial results also indicate that multispectral images of fallow fields can be used as a tool to interpolate between soil sampling locations.

INTERPRETATION: With proper correction, remotely sensed data can serve as a meaningful data source for precision farming. The MADMAC data set does provide convincing evidence of the ability to map crop density and ET; however, the derivation of additional information from remotely sensed data (such as the maps of crop nutrient status, pest infestations and soil properties) would make the application of the data more cost effective for PF applications.

FUTURE PLANS: The registration of the final flights is in process. As the data set is completely assembled, fields that were identified with pest infestations will be examined to see if any signals are evident in the multispectral data prior to the visual identification. Various classification techniques

(supervised and unsupervised classification, regression, and possibly co-kriging) will be investigated to determine the accuracy in the mapping of soil properties (e.g., textual classification) from airborne imagery. As the number of independent physical parameters that can be identified from remotely sensed data is increased, methods to integrate this information to provide decision support for PF systems will be developed.

COOPERATORS: Cristopher Neal, Utah State University; Roy Rauschkolb, Robert Roth, Pat Murphree, and MacD Hartman of The University of Arizona, Maricopa Agricultural Center, Scott Miller, ARS Tucson; Charles Sanchez, Jack Watson, The University of Arizona Cooperative Extension; and Don Post, Soil, Water and Environmental Science Department, University of Arizona.

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GERMPLASM IMPROVEMENT AND CULTURAL DEVELOPMENT OF NEW INDUSTRIAL CROPS

GUAYULE LATEX RUBBER AND RESIN

F.S. Nakayama, Research Chemist; T.A. Coffelt and D.A. Dierig, Research Geneticists

PROBLEM: Loss of latex rubber in the guayule plant begins as soon as the shrub is harvested. In addition, the latex content within the living plant changes with time of year so that the sampling and analytical period for studying latex behavior must be short. These two situations make it imperative that the latex analysis be made rapidly. At present, no accepted rapid, reliable method is available for determining the whole plant latex content that can be used in genetic agronomic, and processing research. Besides this, when guayule latex production is commercialized for making medical products, a waste problem will arise created from the large amounts of bagasse resulting from latex extraction. Ways for properly disposing of the waste must be found.

APPROACH: A rapid method for the estimation of latex content in guayule shrubs will be based on the water extraction process, which would be the one used for commercial latex extraction. Field samples will be chipped directly into and stored in pH-adjusted antioxidant solution. This plant mixture will be further ground in blenders to separate the latex from the plant cell. The homogenate from the blending will first be filtered and the filtrate treated with an acid to coagulate the latex and then be centrifuged to separate the latex for latex content determination. The various steps used in the procedures will be investigated, such as blending time, number of blending-filtration combinations, and sample and filtrate storage times, to determine the variables that are important to optimize latex extraction and analysis. The bagasse waste material after latex extraction will be processed into wood products for possible by-product use.

FINDINGS: Three blender grinding and filtration combinations were needed to get 99% of the extractable latex from the whole plant material (table 1). This combination was used for our laboratory procedure. The chipped ground material could be stored for at least 8 days in a 0.1% Na_2SO_3 solution adjusted to pH 11 and a plant to solution ratio of 1:1 (table 2). In addition, the filtrate from the blending operation could be stored for 7 days without loss of latex (table 3). Thus, the stability of the latex in the chipped shrub-solution and the filtrate solution will allow time for running latex analysis without lost of significant quantities of latex during the harvest period. Approximately 350 latex analyses were completed for two separate early spring harvests which were related to genetic and agronomic studies being conducted at two different locations. A linear relation (Fig. 1) was found between the extracted latex and total rubber content, which was determined by an organic solvent extraction procedure used in evaluating solid rubber (Black et al., 1983). The value of the slope 0.534 gives the extent of latex extraction. However, this is not necessarily the efficiency of extraction, because all the rubber in the plant may not be in the latex rubber form. While work was being focused on whole-plant latex analysis, other analysis showed different latex contents in the different parts of the stem, with the small branches having the highest latex content (table 4). The stem latex content is always higher than the whole plant value because the whole plant contains leaves that do not have any rubber. Particle board was fabricated from bagasse and whole plant guayule chips. Apparently, there is enough adhesive material from the resin and rubber that no additional binding compounds are required with guayule to make particle boards. Analysis of the bagasse indicated that only a small fraction of the total resin material is removed by the water extraction of the latex.

INTERPRETATION: We have developed a rapid method for analyzing whole plant latex content useful for running a large number of samples in a reasonable period of time. Latex and total rubber analyses showed that plants with higher rubber content also had higher extractable latex. A possible way for disposing of waste bagasse material is to use it for making particle boards.

FUTURE PLANS: Use the analytical method developed for following latex content changes as a function of time of year for the various lines of guayule for the genetic, agronomic and latex extraction improvement program. Study the resin and rubber components in the bagasse material. Continue work on particle board fabrication and testing the physical, and insect and other microorganism control properties of the resin and wood products.

REFERENCES: Black, L.T., B.E. Hamerstrand, F.S. Nakayama, and B.A. Rasnick. 1983. Gravimetric analysis for determining the resin and rubber content of guayule. Rubber Chem. Technol. 56:367-371.

COOPERATORS: K. Cornish, USDA-ARS-PWA, Albany, CA; J. Youngquist, USDA-FS, Madison, WI.

Table 1. Number of blending-filtration combinations needed to achieve latex extraction.

	No. of blendings and latex extracted, %			
Sample	1	2	3	4
A	68.6	93.7	99.3	100
B	66.3	92.5	99.8	100
C	67.3	93.0	99.3	100
Avg	67.4	93.1	99.5	100

Note: Extraction solution composed of 0.1% Na_2SO_3 adjusted to pH 10.

Table 2. Effect of storage time on latex extraction from ground plant material (Two-year old, line N6-5)

Time, days	Latex, %
1	2.90 a[1]
2	2.68 a
4	2.63 a
8	2.49 a

[1] Means followed by the same leter are not significant (P<.05)

Note: Storage solution composed of 0.1% Na_2SO_3 at pH 11.0.

Table 3. Effect of filtrate storage on latex content

Time, days	Latex, %
0	2.49 ab[1]
1	2.41 ab
3	2.00 b
7	2.62 a

[1] Means followed by the same letter are not significant (P<0.05)

Table 4. Latex content and stem size

Sample	Latex, %
Small (≤0.5 cm)	5.03
Medium (0.5-1.0 cm)	4.35
Large (≥1.0 cm)	3.47

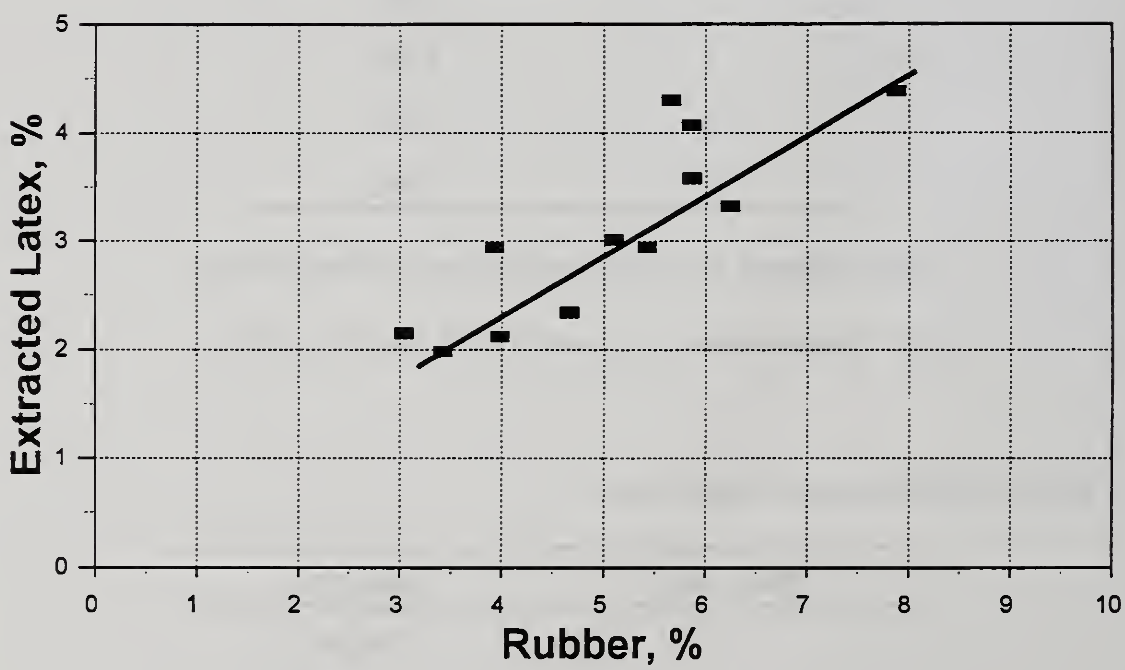

Figure 1. Relationship between total rubber content and extractable latex
($R^2 = 0.73$; $Y = 0.362 + 0.534 X$)

GUAYULE GERMPLASM EVALUATION AND IMPROVEMENT

T.A. Coffelt and D.A.Dierig, Research Geneticists; and F.S. Nakayama, Research Chemist

PROBLEM: Latex allergies are becoming a serious health problem, so ample sources of hypoallergenic latex are needed. One possible source is guayule, but higher yielding, faster growing, and easier to establish germplasm is needed for it to be successful as a viable new crop. The objectives of these studies were to: (1) evaluate the survival rate and plant height and width of advanced germplasm lines one and two years after transplanting; (2) determine the effects of plant age on plant height, width and latex content; (3) determine the effect of location on plant growth and latex content; (4) determine the effect of harvest date on latex content; (5) compare latex contents and plant growth of plants established either by transplanting or direct seeding; and (6) compare the regrowth rate of one and two year old plants harvested by clipping at ground level.

APPROACH: Objective 1: Field tests for evaluating plant survival rate, height and width were conducted at The University of Arizona, Maricopa Agricultural Center (MAC), on 26 advanced lines compared to two checks (11591 and N565). Lines were transplanted in April 1995 and survival ratings and plant height measurements taken in February 1996, and plant survival, height and width measurements taken in March 1997. Lines were planted in a randomized complete block design with four replications. **Objective 2**: Four lines were transplanted at MAC and at the Marana Agricultural Research Farm in the springs of 1995 and 1996. One and two year old plants were evaluated for plant height, width, and latex content in the spring of 1997. Lines were planted in a completely randomized design with four replications at both locations both years. **Objective 3**: The plants used in objective 2 were also used to determine the effect of location on plant height, width, and latex content. **Objective 4**: Three lines (O16-1, Cal-6, and Cal-7) were transplanted at Marana in 1995 and one line (Cal-6) direct seeded and transplanted in 1995. Four plants of the three transplanted lines were sampled every two weeks starting December 4, 1995, to November 4, 1996, and analyzed for latex content. The same procedure was used to compare the direct seeded and transplanted plants of Cal-6 starting January 14, 1997, to March 18, 1997. **Objective 5**: Four lines (CAL-6, CAL-7, UC101, and N6-5) were direct seeded and transplanted in the spring of 1995 at Marana. Two year old plants were evaluated in the spring of 1997 for plant height, width, and latex content to determine the effects of planting method. Lines were planted in a randomized complete block design with four replications. **Objective 6**: One and two year old plants harvested in objectives 1 and 2 plus two year old plants harvested in objective 5 have been monitored monthly for ability to regrow and measured for plant height and width.

FINDINGS: Objective 1:G7-11, G7-14, G7-15, N9-4 and N7-2 were rated the best overall lines for plant growth (table 1). N8-5, N7-5, G1-10, N6-2, P10-4 and P10-5 were rated the worst lines overall for plant growth. There were significant differences among lines in plant growth rate for the two years. For example, G7-14 and G7-15 grew the most the first year, while 11591, N565 and eight other lines grew more the second year. All lines except N565 had a plant height to width ratio greater than one. **Objective 2**: Two year old plants were significantly taller, wider and had more latex than one year old plants (table 2). **Objective 3**: Location had more affect on plant height, width, and latex content than plant age or line. Plants grown at Marana were significantly taller, wider and higher in latex than those grown at MAC (table 2). **Objective 4**: In the first experiment, the three lines averaged about 2% latex in December 1995, rising to almost 11% in March 1996, dropping to below 1% in June and July 1996, and rising again to over 4% by October 1996. In the second experiment, two year old direct seeded plants of Cal-6 had a lower percentage of latex than transplanted plants in January and early February 1997, but were essentially the same by mid-February 1997 (table 3). Plants from both treatments increased significantly in latex content

by mid-March. **Objective 5**: Plants from the direct seeded plots were generally higher in latex than those from the transplanted plots. However, preliminary results indicate a significant line by planting method interaction. Plants from direct seeded plots were taller and wider than plants from transplanted plots (table 4). **Objective 6**: Preliminary results on regrowth indicate significant differences among lines for the ability to regrow after clipping. G7-11, G7-14, and G7-15 are significantly better than P2-BK, N7-11, P10-13, C16-1, CAL-6, CAL-7, UC101, and N6-5 for regrowth potential.

INTERPRETATION: Variability within and among guayule germplasm lines was significant for all traits studied in all experiments, thus indicating room for improvement in these traits through selection and other breeding techniques. The lines evaluated in this study should serve as excellant sources of germplasm for cultivar development in guayule. Six germplasm lines (AZ-1 to AZ-6) were jointly released with The University of Arizona Agricultural Experiment Station in 1997. These lines were released for their higher rubber content, larger plant size and/or their ability to regrow. Although two year old plants were generally higher in latex and larger than one year old plants, significant line by age and line by location interactions indicate the opportunity exists for selecting lines that could be harvested in 12 to 18 months under the right environmental conditions. More experiments need to be conducted to identify the environmental factor(s) that are responsible for the significant differences in plant growth between MAC and Marana. Results from the dates of harvest studies indicate that latex production appears to be cyclical in guayule and the spring months (March and April) are probably the optimum harvest time for maximum latex production. While transplants are initially larger than direct seeded plants, two year old plants were generally larger in direct seeded plots and had a slightly higher latex content indicating that direct seeding is a viable method for plant establishment. Regrowth from plants clipped at ground level indicates the significant effects of line on the ability of plants to regrow. Additional studies on other harvesting methods need to be conducted in order to determine the optimum harvest method. The most significant observation was the damage caused by the salt marsh caterpiller to some regrowth plants at MAC. This was the first observation of this insect pest feeding on guayule. No damage was observed to one and two year old plants in the same plots.

FUTURE PLANS: We will continue to evaluate germplasm lines for superior traits such as faster growth, high seed germination rates, high latex percentage, high biomass, faster regrowth and reduced variability among plants. We will cooperate in developing harvesting schedules and methods for maximizing latex yield. These studies will all involve close cooperative work with scientists at the various locations involved in guayule research.

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Table 1. Plant stands, heights and widths of 28 guayule lines transplanted at MAC on April 6, 1995 after one and two years growth.

LINE	1996 STAND (%)	1996 HEIGHT (cm)	1997 STAND (%)	1997 HEIGHT (cm)	1997 WIDTH (cm)
G7-14	99.3	40.6	98.5	52.1	45.9
P10-4	97.0	27.6	91.0	34.6	28.9
G7-15	97.0	40.5	96.3	49.0	44.0
11591	97.0	33.7	96.3	54.7	46.1
N7-11	97.0	30.0	95.5	40.0	36.4
P3-11	95.5	30.6	92.5	43.0	38.1
C16-1	94.8	25.5	89.3	37.7	34.9
N9-3	94.0	29.3	90.0	46.5	41.5
N6-3	91.5	27.0	86.3	38.9	34.8
G1-10	91.3	24.0	89.8	37.1	31.4
N8-10	90.8	27.0	88.5	42.2	38.7
P10-13	90.5	30.8	90.0	41.1	38.3
P2-BK	89.3	28.3	83.5	40.9	38.1
G7-11	88.5	32.7	85.3	48.1	44.5
N12-18	87.8	27.4	80.5	40.3	35.6
P10-5	86.0	24.2	82.3	36.8	30.9
G1-16	86.0	29.1	79.0	43.1	39.8
N6-2	84.5	24.3	77.5	35.3	31.3
P11-1	84.5	24.7	78.3	38.1	33.8
N13-1	83.0	30.0	82.3	46.8	42.1
O16-1	82.3	29.2	80.5	48.1	43.2
N565	80.0	25.1	79.3	41.8	43.7
N7-5	79.8	24.0	72.8	34.0	31.6
N8-5	75.3	23.8	74.5	35.1	32.2
N7-2	75.0	31.2	72.5	48.9	44.5
N8-1	61.0	26.2	58.0	42.7	39.0
N9-4	61.0	31.9	61.8	51.1	47.3
P10-3	56.5	25.0	56.5	40.5	37.1
LSD	15.6	5.2	16.7	6.5	6.2

Table 2. Main effects (plant age, location, and line for plant height, width, and latex content of four lines grown at two locations).

MAIN EFFECT	HEIGHT (cm)	WIDTH (cm)	LATEX (%)
AGE			
ONE YEAR	42.8 b	42.2 b	0.93 b
TWO YEARS	57.4 a	57.2 a	1.46 a
LOCATION			
MAC	39.4 b	33.9 b	0.60 b
MARANA	60.8 a	65.5 a	1.79 a
LINE			
C16-1	41.6 c	42.0 c	1.65 a
G7-11	50.5 b	52.4 b	1.13 b
G7-14	55.5 a	55.3 a	0.94 b
G7-15	52.7 ab	49.1 b	1.07 b

Table 3. Latex content (%) in Cal-6 established either by direct seeding or transplanting.

SEEDING METHOD	14 JAN 1997	28 JAN 1997	11 FEB 1997	25 FEB 1997	11 MAR 1997	18 MAR 1997
DIRECT	0.5	2.3	2.4	2.2	1.7	6.3
TRANS	1.6	4.2	3.0	2.0	2.0	6.2

Table 4. Plant height, width, and latex content of two year old plants of four lines grown from seed and transplants at Marana 1995-1997.

	HEIGHT (cm)		WIDTH (cm)		LATEX (%)	
LINE	DIRECT	TRANS	DIRECT	TRANS	DIRECT	TRANS
UC101	62.3	55.1	74.0	64.2	1.72	1.12
CAL-6	56.5	51.9	63.9	63.8	1.13	1.35
CAL-7	58.4	51.8	67.1	58.5	1.36	1.14
N6-5	63.6	58.6	74.7	65.1	1.55	1.48
MEAN	60.2	54.4	69.9	62.9	1.44	1.27

GUAYULE BREEDING AND GENETICS

D.A. Dierig and T.A. Coffelt, Research Geneticists; and F.S. Nakayama, Research Chemist

PROBLEM: Potentially guayule could supply industry with a hypoallergenic source of latex for medical and other consumer products. Guayule is not yet a commercialized crop, although some private companies are trying to provide a source of this latex to the marketplace. Improving rubber and latex yields in guayule is a necessary component to their success. The objective of this study was to improve rubber or latex yields of guayule through plant breeding.

APPROACH: The proportion of genetic and environmental influences of growth characteristics and rubber, latex and resin production was measured. Broad sense heritability was calculated on five measured traits. Plants were propagated through tissue culture from a single plant and assumed to be genetically identical. Plants were also seed propagated. Amounts of variation for growth and yield were measured and compared between the two treatments. Both treatments were field transplanted at The University of Arizona, Maricopa Agricultural Center (MAC), in a randomized complete block design experiment. Seedlings were transplanted in the field April 1995. Plots were two beds wide (1m apart) and 5.7 m long (16 plants / bed), four replications, planting density of 27,677 plants/ha. Three different lines were studied. Plants were two years old at harvest. Plant heights were measured on all plants within plots both years. Plant widths were measured only on harvested plants. Two plants per plot were harvested to determine fresh weight and contents of latex, rubber, and resin. Plant dry weights were determined by harvesting separate plants for oven-drying. Plants were harvested over a four-week period to avoid storage effects such as latex degradation. Whole plants, including roots were harvested, weighted, and chipped into a solution containing antioxidant. An estimate of heritability was calculated for each measured trait. The proportion of phenotypic variation was a result of the genetic differences in the population. Heritability (broad sense) was estimated by the formula $H(B) = V(G) / V(P)$, where seed propagated plants represented the total phenotypic variance $V(P)$ since environmental effects cannot be separated from genotypic effects. The tissue cultured plants represented environmental variance $V(E)$ since all should be clones of a single plant (single genotype). Any variation in these plants was attributed to environmental effects. Therefore, genotypic variation $V(G)$ is derived from the formula $V(P) = V(G)+V(E) + V(GE)$. The genotype-by-environment interaction $V(GE)$ was assumed to be 1.

The effect of plant spacing on growth and yield was also studied. Two different breeding lines were field transplanted on March 6, 1996, at MAC. Plants were spaced at seven and 14 inches apart in four replications. The 14 inch treatment was planted in a straight row while the 7 inch were planted in a staggered arrangement on the raised bed. Plant heights were measured May 17 and November 20, 1996; May 15 and September 15, 1997. They will harvest plants in Spring 1998.

Six germplasm lines were publically released this past year jointly with The University of Arizona. These lines were tested experimentally as the following: AZ-1 as C16-1, AZ-2 as G7-11, AZ-3 as G7-15, AZ-4 as N7-bulk, AZ-5 as N7-11, and AZ-6 as P2-bulk. The lines were tested in yield trials and compared with standard lines for comparison.

RESULTS: Table 1 contains the values for the measured traits, standard deviations, and coefficient of variation (C.V.). The C.V. for plant height and width of all three lines were, overall, between two and three times higher in seed compared to tissue culture derived plants. C.V. for rubber and resin contents were also higher in the seed propagated plants for lines G7-11 and N7-11. Line P2-bulk had C.V. values that were nearly equal. This was also the case with the latex content coefficient of variation between seed and tissue cultured plants. Table 2 contains heritability estimates for five traits. These range between 45 and 73%.

Table 3 contains plant height measurements for the two lines planted at seven and 14 inch spacing. Plant heights were not affected by spacing in the first year and a half of growth for either line used in the study at any of the four dates of measurement.

AZ-1 produced more rubber after two and three years and more biomass after three years than the check. AZ-2 produced more biomass after two years and grew faster than the checks. AZ-3 produced the highest biomass after three years of all lines. AZ-4 and AZ-5 were released for their faster regrowth after an initial harvest. AZ-5 is more uniform in plant traits than AZ-4. AZ-6 produced more rubber after two and three years than all but one other line.

INTERPRETATION: The higher values for C.V. in seed compared to tissue culture derived plants demonstrate that apomixis is facultative. The degree of sexual or apomictic reproduction varies between breeding lines. Apomixis does not exclude genotypic variability. Heritability estimates showed that a large proportion of the variability occurring in the measured traits can be attributed to the genotypic variance. Therefore, improvement of these traits can be achieved through plant breeding.

Twice the number of plants can be planted when the 7 instead of 14 inch spacing is used. The common practice now is to harvest plants after three years of growth. This study so far suggests that when the number of plants is doubled, twice the biomass is produced and potentially rubber yields are doubled. There is also the potential with a closer spacing to harvest plants after two years instead of three. We publically released line G7-11 (as AZ-2) and N7-11 (as AZ-5). The larger plants, line G7-11, could fit well into the two-year harvest scheme.

Public release of the new lines should make development of higher yielding and faster growing cultivars of guayule possible.

FUTURE PLANS: The effect of plant spacing on biomass, rubber, resins, and latex production will be examined when plants are harvested next spring. The heritability study is completed.

COOPERATORS: D.T. Ray, The Univ. of Arizona, Plant Science Department, Tucson, AZ; R. Roth, The Univ. of Arizona, Maricopa Agricultural Center, Maricopa, AZ.

Table 1. Values for the measured traits of three breeding line, standard deviations, and coefficient of variation (C.V.) between seed propagated and tissue culture plants.

	G7-11 (AZ-2)		**N7-11 (AZ-5)**		**P2-Bk (AZ-6)**	
	yr 1	yr 2	yr 1	yr 2	yr 1	yr 2
Seed						
Ht.(cm)32.6	47.4	30.0	39.9	28.3	40.8	
Std.dev 15.9	14.6	8.1	10.9	9.6	10.8	
C.V.	48.7	30.8	27.0	27.3	33.9	26.5
Tissue Culture						
Ht.(cm)30.75	56.4	37.7	55.7	19.7	30.4	
Std.dev 5.4	8.3	4.4	6.2	3.9	2.7	
C.V.	17.6	14.7	11.7	11.1	19.8	8.9
Seed						
Width (cm)		44.6		35.51		38.18
Std. dev.		15.63		12.48		13.5
C.V.		35.0		35.14		35.3
Tissue Culture						
Width (cm)		55.8		55.45		37.39
Std. dev.		12.2		9.09		5.65
C.V.		21.9		16.4		15.1
Seed						
Rubber (%)		5.53		6.27		6.42
Std. dev.		1.63		0.93		1.28
C.V.		29.47		14.83		19.9
Tissue Culture						
Rubber (%)		5.15		6.42		4.47
Std. dev.		0.63		0.53		0.86
C.V.		12.23		8.25		19.2
Seed						
Resin (%)		10.34		9.83		9.8
Std. dev.		1.22		1.51		0.87
C.V.		11.8		15.36		8.87
Tissue Culture						
Resin (%)		9.33		9.95		9.18
Std. dev.		0.72		0.79		0.83
C.V.		7.71		7.93		9.04
Seed						
Latex (%)		1.89		2.55		2.31
Std. dev.		1.09		1.08		1.12
C.V.		58.0		42.3		48.5
Tissue Culture						
Latex (%)		0.29		2.21		1.58
Std. dev.		0.18		0.69		0.58
C.V.		62.0		31.2		36.

Table 2. Broad sense heritability estimates (%) for two breeding lines.

	N7-11
Latex %	59.6
Plant Width	45.3
Plant Height	66.8
Resin %	72.9
Rubber %	67.8

Table 3. Height measurements from four dates of two germplasm lines at 7" and 14" plant spacings

Line and plt.spacing	**May 5, 1996**		**Nov 20, 1996**		**May 17, 1997**		**Sept 15, 1997**	
	Ht.(cm)	std.dev	Ht.(cm)	std.dev.	Ht.(cm)	std.dev.	Ht.(cm)	std.dev.
G7-11 7"	11.96	4.9	32.38	13.33	40.82	16.34	50.49	20.84
G7-11 14"	13.77	5.16	32.13	13.38	41.13	15.16	52.29	20.55
N7-11 7"	8.84	2.73	21.17	6.28	32.39	7.3	36.87	9.86
N7-11 14"	10.39	3.02	21.2	7.0	29.3	7.86	35.13	11.09

LESQUERELLA GERMPLASM IMPROVEMENT

D.A. Dierig, B. Kaufman, T.A. Coffelt, Research Geneticists; and
Pernell Tomasi, Biolological Technician

PROBLEM: Lesquerella seed could provide U.S. industrial markets with a source of hydroxy fatty acids. In the past, these markets have been satisfied by imports of castor for many types of industrial applications. The unique chemical structure of the oil from Lesquerella, although similar to castor, offers distinct advantages for development of other applications as well as a partial replacement for castor oil. The focus of our research is to evaluate, develop, and improve *Lesquerella* germplasm through plant breeding,

APPROACH: Seeds from some of germplasm seed collections were field grown at USWCL for seed increase and evaluation. When plants began to flower, screen cages were placed over individual plots, and supplied with a nucleus of honey bees for pollination. Plant growth measurements were taken throughout the season. After harvest, seeds from each accession were analyzed for oil content and composition.

Three recurrent populations for increased oil content, hydroxy fatty acid content, and oil and hydroxy fatty acid yields were repeated for the 1996-1997 season. Five hundred plants from each population were harvested and analyzed and compared to an unselected check population.

A male sterile F3 segregating generation was planted in greenhouses at USWCL. F3 seeds resulted from crosses between male sterile (no pollen) and male fertile (pollen) plants. Fifty different lines with over two thousand plants were scored at flowering for the male sterile trait. Some were reciprocal crosses, to determine if the trait is passed along only through the maternal parent (cytoplasmic inheritance). Ratios of sterile and fertile plants indicate the number of genes responsible and the dominance relationship.

Yellow seeded plants were compared to the normal orange/brown color and grown in pollination cages. Plants producing yellow seed were selected at harvest. Seed colors were scored on Munsel charts and sent to USDA-ARS-NCAUR to compare the color of the resulting oils.

Environmental effects on the development fatty acid profile were examined in maturing seeds. Flowers of 600 individual flowers were tagged while growing in the field at two locations. Age of the seeds was determined from first day of flowering to harvest of the pod (DAF). Seeds were harvested at 4-day intervals from 15 to 71 DAF. Seed samples were stored at -80° C following harvest. After seed collections were completed, samples were arranged in three replications of a completely randomized design and analyzed on a gas chromatograph. Seed weight and fatty acids were evaluated.

Plants were measured at the beginning of anthesis an attempt to find early predictors associated with upright growth habits and seed yield. Plants were measured in the greenhouse and transplanted into field plots. Twenty-four breeding lines with 50 plants each were measured. Measurements of primary and secondary branches, plant width, branch angle, leaf shape, and branch thickness were taken. Plant heights, ratings of growth habit, seed yield, and number of pods from individual plants were measured at harvest.

A procedure is being developed to produce haploid plants for use in mutation treatments of seed. Flower bud and petal lengths were measured and correlated to the meiotic stage of microspore cells most suitable to regenerate into a double haploid plant. Plants will be screened for fatty acid profile, or oil content mutants.

A procedure was developed to isolate DNA from plant tissue with high carbohydrate levels. Fifty Random Amplified Polymorphic DNA (RAPD) primers were used to screen DNA samples from 10 male sterile (MS) and 10 fertile plants to identify the markers associated with the MS trait.

DNA samples from 52 taxa of Lesquerella and 29 Physaria were screened with both RAPD and Amplified Fragment Length Polymorphism (AFLP) molecular markers to the degree of relativeness. Each taxon is represented by DNA pooled from ten plants.

FINDINGS: Table 1 lists the results from the evaluation of collected species grown at USWCL.

The recurrent population for high oil content ranged between 14 and 32%. The population mean was 25%, compared to an unselected population of 20%. These values are uncorrected for moisture and as a result are lower than the true content. Analysis for the high lesquerolic population is not yet completed.

Ratios from F3 generation confirm the previous year results. Male sterility results when one or two nuclear genes this are homozygous recessive. There are modifier genes that restore different degrees of fertility.

Results of the yellow seed oil color analysis indicated that seeds with darker seed coats contained darker oil. The Gardener unit was 14 for the brown seed samples and 13 for yellow.

Early measurements taken to predict final plant yields correlated among themselves (secondary branches to plant width $r = 0.88$) but not to seed yield. Three of the variables accounted for only 20% of the variability for seed yield. No unique characteristics were detected between high and low seed yield populations until maturity. Significant differences were found between high and low populations for height, width, and dry weight.

Environmental effects influenced fatty ester profiles. Lesquerolic acid content was stabilized by 31 DAF at one location and about 25 DAF at the second location.

Petal and bud lengths were both highly correlated ($R^3 = 0.71$) to the necessary meiotic stage to produce haploid plants from microspore culture.

Primers OPL-02, OPL-04, OPL-19, OPZ11, and OPZ14 amplified potentially diagnostic DNA segments for fertile and sterile genotypes. The genome size of *L.fendleri* is estimated to be 1.7×10^9 bp. Eighty-six percent of the RAPD markers were polymorphic, indicating high amounts of genetic variability.

INTERPRETATION: Studying the inheritance of male sterility in lesquerella will allow us to control this trait. It appears relatively frequently in a population. We do not know what effect it has on seed production There is also the possibility of utilizing the trait later for hybrid seed production.

.Yellow seed may have an importance in the cosmetic industry. Decoloration from the seed coat pigment present in the oil must be removed by hydrogenation.

Since bud and petal lengths are highly correlated to microspore meiotic stage, we can use these measurements to find the correct stage to culture plants instead of using the much more tedious cytological examination.

Although the study of early measurement to predict final seed yield found no high correlations to yield, the study indicates that traits may be selected for or against without a decline in yield. These traits may still be beneficial (for example, stem thickness to improve combine harvest).

Based on data from the fatty acid profile study, seed could be harvested for lesquerolic acid between 25 DAF and 31 DAF.

FUTURE PLANS: A yellow seed coat germplasm line and a male sterile line will be released this year. It is uncertain whether the recurrent selection for improved oil will continue. This is labor intensive and cut backs in technical help may limit this work. Evaluation and seed increase of germplasm from collection trips will depend on availability of outside funding. The study of fatty acid development in seeds is in progress for a second year. An experiment is planned at two locations to determine heritability on yield related traits especially plant height. We are collaborating with the ARS Salinity Laboratory, Riverside, California, on a salinity study. This will provide formation of a salt tolerant population. Production of haploid plants will be attempted through microspore culture and confirmed through flow cytometery. Diagnostic DNA markers for male sterility will be confirmed on larger populations.

COOPERATORS: R.L. Roth, J.M. Nelson, Univ. of Arizona, Maricopa, AZ; D.T. Ray, Univ. of Arizona, Tucson, AZ; T.A. Abbott and B. Phillips, USDA, ARS, NCAUR, Peoria, IL.

Table 1. Results of evaluation of Lesquerella species increased and evaluated at the USWCL 1996-97.

Accession	Species	Origin	Stand (plts)	1st Flower (date)	Seed yield (g / plt)	[2]Seed Oil (%)	Lesquerolic acid (%)
2925	*angustifolia*	OK	104		12.6	11.79	51.35
2927	*angustifolia*	OK	104		23.2	n/a	51.68
2219	*argyraea*	TX	71	Mar. 3	13.66	22.34	56.34
3011	[1]*auriculata*	OK	104	Jan. 23	7.2	n/a	4.95
1869	*cinerea*	AZ	104	Feb. 24	29.00	20.79	51.69
1861	*cinerea aff.*	AZ	40	Mar. 7	1.1	14.90	50.64
2202	*densifolia*	TX	104		0.4	n/a	62.60
2306	*fendleri*	TX	27	Jan. 23	17.31	16.78	49.41
2305	*fendleri*	TX	36	Jan. 13	37.08	17.40	48.82
2302	*fendleri*	TX	104	Mar. 7	169.2	20.33	48.25
1818	*fendleri*	AZ	104	Jan. 13	220.85	20.98	50.54
1880	*fendleri*	AZ	188	Mar. 7	62.78	20.90	51.12
1852	*fendleri*	AZ	90	Mar. 7	9.53	17.21	62.31
1851	*fendleri*	AZ	122	Mar. 7	4.11	19.21	49.65
1932	*fendleri*	AZ	200	Mar. 7	7.64	18.84	46.25
1904	*fendleri*	AZ	314	Mar. 24	31.51	21.83	50.64
2226	*fendleri*	TX	29	Jan. 23	5.96	17.38	49.94
1809	*fendleri*	AZ	104	Jan. 23	186.98	21.76	52.88
1817	*fendleri*	AZ	104	Jan. 23	109.39	19.07	51.00
1836	*fendleri*	NM	152	Mar. 7	35.8	23.55	50.2
1840	*fendleri*	NM	105	Mar. 7	22.41	20.67	50.16
1909	*fendleri*	NM	418	Mar. 24	6.02	14.43	52.39
1842	*fendleri*	NM	123	Mar. 7	42.38	21.5	64.06
1830	*gordonii*	AZ	31	Jan. 13	0.8	19.47	57.55
2928	*gracilis*	OK	104		0	n/a	59.76
2926	*gracilis*	OK	104		4.1	9.48	49.77

2246	*grandiflora*	TX	104		23.2	25.26	48.67
2247	*grandiflora*	TX	104	Nov. 20	61.7	28.19	53.89
A2243	*grandiflora*	TX	274	Nov. 20	0.24	21.20	50.42
1930	*intermedia*	AZ	222		1.1		
1879	*intermedia*	AZ	104	Mar. 7	0	19.75	47.32
1882	*intermedia*	AZ			8.4	n/a	48.11
1902	*kaibabensis*	AZ	40	Feb. 3	0.7	n/a	51.13
A2228	*lasiocarpa*	TX	104	Mar. 7	2.0	n/a	53.03
2217	*lasiocarpa*	TX	104	Jan. 13	11.8	24.00	52.56
2232	*lindheimeri*	TX	104		4.00	21.62	81.65
3186	*multiceps*	UT	1		11.3	n/a	50.73
A3219	*pallida*	TX	25		28.5	n/a	50.14
3103	*parviflora*	CO	104		3.6	n/a	41.41
A1802	*purpurea*	AZ	2		0.2	n/a	36.67
1875	*rectipes*	AZ	158	Mar. 7	20.9	24.46	48.20
1876	*rectipes*	AZ	82	Mar. 7	0	n/a	58.42
2250	*recurvata*	TX	104		3.8	n/a	67.26
2204	*recurvata*	TX	104		1.3	n/a	68.55
A2251	*sessilis*	TX	104		6.3	16.84	68.56

[1] *L. auriculata* has a different hydroxy fatty acid in its seed-oil that is predominant. This species is higher in the C20:2-OH hydroxy fatty acid, auricolic acid.

[2] When less than 2 grams of seed were available, oil content could not be accurately analyzed.

VERNONIA GERMPLASM IMPROVEMENT

D.A. Dierig and T.A. Coffelt, Research Geneticists;
F.S. Nakayama, Research Chemist; and Floyd Adamsen, Soil Scientist

PROBLEM: Epoxidized oils are widely used for plasticizers and additives for flexible polyvinyl chloride (PVC) resins. Part of this market is satisfied by the epoxidation of either soybean or linseed oil. The composition of the seed-oil from *Vernonia galamensis* and its epoxidized product have superior and unique qualities for industrial uses. If production and oil processing could be cost effective, relative to soybeans, significant quantities could be utilized. One unique potential use might be as drying agents in reformulated oil-based or alkyd-resin paints. The United States presently manufactures 1230 million liters of these types of paints and varnishes annually. Drying agents currently used in them are major air pollutants, releasing volatile organic compounds (VOC's). Use of vernonia oil in these formulations would greatly reduce the VOC pollutants, and create 150,000 ha of an alternative crop for farmers to grow. Another use could be in metal or wood coatings. *V. galamensis* is a native of Africa and only flowers and produces seed under short day conditions. This characteristic prevented successful cultivation within the continental U.S. We successfully utilized an accession which flowered any time of the year, to produce hybrids containing this trait. The objective of this research is to develop high yielding germplasm adapted to the U.S. and evaluate vernonia's agronomic potential as a new oilseed crop.

APPROACH: On April 29, 1997, six day-neutral hybrid lines and a parent check line were seeded at the USWCL field. The seeding rate was four grams per nine meter row plots. Plots were four rows wide, spaced a half meter apart with drip irrigation. Row spacing in previous years had twice the space between rows. It became apparent that the closer spacing slowed vegetative growth. Weekly drip applications of fertilizer began August 18 and continued until September 29, 1997. A fungicide, Subdue, was applied through the drip irrigation lines on July 18 and August 13, 1997. Three lines of *Euphorbia lagascae*, selected for non-shattering, were also direct seeded in this experiment. Euphorbia, like vernonia, is also a source of vernolic acid and is native to Spain. Planting was in cooperation with Oregon State University. Euphorbia lines were planted at a rate of 9.5 g per nine meters. Germination tests were performed on all ten lines (seven Vernonia and 3 Euphorbia). The experiment was a completely randomized block design with three replications. Stand counts were taken on Euphorbia plots on May 16, 1997. Vernonia plots were not counted because of high germination rates. At harvest, on September 12, plant biomass was weighed and recorded. Seed was collected from plots 4 rows wide by 2 meters long to determine yields. Seeds were analyzed for oil and fatty acid composition.

Seven surface soil samples were collected from Euphorbia plots. Soils were analyzed for Cl, NO3, SO4, and electric conductivity (EC).

Seeds of a segregating population from plants with improved seed retention were transplanted into the field this season. After flowering plants were evaluated.

FINDINGS: This 1997 season planting was the most successful vernonia planting we have had. There was good germination and uniform stands. Plants remained healthy until maturity with no disease symptoms. The most important factor seems to be the drip irrigation. In previous years disease devastated fields. Last year we applied Ridomil fungicide as a soil drench when symptoms appeared in late July when plants were flowering. Symptoms from last year included sudden wilting, and girdled, stunted roots. The results of the harvest are included in table 1.

Results from a soil analysis indicated that surface soils were very salty (table 2). Euphorbia lines germinated and plant stands were fairly uniform. Plants had four to eight true leaves when they began to turn brown and die. Within two weeks there were no Euphorbia plants alive in any of the three lines.

None of the plants evaluated for improved seed shattering exhibited the trait. Plants were planted late in the season and some have not yet reached maturity.

INTERPRETATION: The variety trial was a success this year. Overall, yields have increased because of improved management practices such as fungicides, fertilizers and drip irrigation. This year's crop was the most productive ever grown here. The work on this crop over the past few years has not emphasized improvements of specific lines. Seed retention has been a major focus with the hope that it will allow a significant increase in yields causing more seeds to remain on the plant. The end of funding from the Advanced Materials from Renewable Resources Program has limited our effort. This is a very promising crop with a large potential market. New markets are being developed by industry. Improvements in yields from plant breeding and more efficient oil extraction methods are the necessary components to move this crop to commercialization.

The soil analysis indicated that vernonia is very adapted to a wide range of soils. This crop can be successfully grown in saline soils or in the Eastern U.S. under more acidic soils. Euphorbia plants all died after germination under the same conditions. Euphorbia does not appear to have as extensive of a range of growing environments as vernonia.

FUTURE PLANS: Goals for next year are to increase and characterize the selected, non-shattering plants. Some of the same selections in a trial will be grown to compare the 20 and 10 inch row spacing and various nitrogen treatments. There will be limited plant breeding for other yield traits.

COOPERATORS: D.T. Ray, Univ. of Arizona, Tucson, AZ; Ali Mohamed, Virginia State University, Petersburg, VA; P.K. Martin, Vertech Industries, Plano, TX

Table 1. Results from the 1997 yield trial of six vernonia hybrid lines and a control (A0399) including seed yield, oil, and specific fatty acid contents at USWCL, Phoenix, Arizona.

Line #	Rep	Seed Wt	Seed Yield	**Oil**	C18:1	C18:2	**Vernolic acid**
		(g)	(kg/ha)	(%)	(%)	(%)	(%)
6A-25-11	I	174.45		**41.57**	4.37	13.58	**75.03**
	II	122.43		**35.40**	4.70	14.05	**73.66**
	III	40.37		**35.37**	4.99	14.54	**72.77**
		179.08	440.66	37.45			73.82
15D-10-12-2	I	88.87		**36.56**	4.50	12.86	**75.26**
	II	128.92		**36.96**	4.68	13.93	**74.04**
	III	92.98		**34.90**	4.44	14.15	**74.09**
		103.59	254.90	36.14			74.46
29E-OR2	I	172.18		**34.86**	4.95	14.99	**72.28**
	II	118.21		**35.29**	4.22	12.85	**75.69**
	III	108.82		**35.91**	4.45	12.96	**75.13**
		133.07	327.44	35.35			74.37
49B-OR1	I	261.82		**35.84**	4.63	12.42	**75.34**
	II	144.53		**37.09**	4.93	14.16	**73.39**
	III			**30.32**	5.49	15.66	**70.53**
		203.18	499.94	34.42			73.09
63B-1	I	203.18		**34.56**	4.00	13.45	**75.29**
	II	240.61		**36.28**	4.37	13.45	**74.55**
	III			**34.93**	5.07	15.46	**71.21**
		221.89	546.00	35.26			73.69
64B-3-5	I	56.35		**35.91**	5.32	15.17	**71.60**
	II	114.77		**37.01**	4.52	13.23	**74.90**
	III	75.04		**34.26**	5.00	15.76	**71.16**
		82.05	201.90	35.73			72.55
AO399	I	196.64		**35.80**	5.14	13.52	**73.77**
	II	233.98		**37.37**	4.29	13.71	**74.71**
	III	132.11		**32.14**	4.87	13.75	**73.28**
		187.58	461.56	35.10			73.92

Table 2. Salinity analysis of surface soil at USWCL. Results are the average of six samples taken June, 1997.

C1	19,791 mg/l or 558 me/l
N03-/N	220.1 mg/l or 3.1 me/l
SO4	20,006.7 mg/l or 209.3 me/l
Total EC	770

LABORATORY SUPPORT PROGRAMS

ELECTRONICS ENGINEERING LABORATORY

D.E. Pettit, Electronics Engineer

The electronics engineering laboratory is staffed by an electronics engineer whose duties include design, development, evaluation, and calibration of electronic prototypes in support of U.S. Water Conservation Laboratory research projects. Other responsibilities include repairing and modifying electronic equipment and advising staff scientists and engineers in the selection, purchase and upgrade of electronic equipment. Following are examples of work orders completed in 1997:

- Designed the Generation 2 probes, inverting switching regulator positive and negative DC power modules, and water flow monitoring power interlock device.
- Modified the Audio Amplifier for Tone Generator on a Mini-Hydrization Camera Unit.
- Repaired and modified a variety of equipment throughout the year, including CR21X data loggers and CR7 data loggers, various hand-held guns, polycorders and polycorder cables, the anemometers, A CO2 controller system, and A CO2-IR analyzer unit, CP units, neutron and hydro probes.

COMPUTER FACILITY

T.A. Mills, Computer Specialist

The computer facility is staffed by one full-time Computer Specialist and one Computer Assistant. Support is provided to all Laboratory and Location Administration Office computer equipment and applications. The facility is responsible for recommending, purchasing, installing, configuring, upgrading, and maintaining the Laboratory's Local and Wide Area Networks (LAN, WAN), computers, and peripherals. The LAN utilizes up to 10Base-T hubs and one 12 port 100VG hub. A high speed switching hub currently connects one 48 port 10Base-T hub and the 100VG hub to a standard Ethernet backbone. All other hubs are directly connected to the standard Ethernet backbone or daisy chained through other hubs. This configuration provides over 160 ports to six Laboratory buildings.

A local router and a 56kbs lease line connects our Laboratory to Arizona State University. ASU provides our LAN access to the WESTNET WAN and the Internet. The Laboratory maintains a Class C block of Internet addresses operating under the domain uswcl.ars.ag.gov.

The Laboratory LAN is comprised of seven servers operating under UNIX, Netware 3.12, or Windows NT 4.0. End users operate mainly under Windows 95 with a few OS/2 and Windows NT workstations. Services such as E-Mail, print, file, remote access, and backup are provided by the LAN. The Laboratory maintains its own Web Server, and can be accessed at www.uswcl.ars.ag.gov.

Future projects include expanding the 100 Megabit LAN, replacing the standard Ethernet backbone with fiber optics and improving Internet access speeds.

LIBRARY AND PUBLICATIONS

Scott Gardner, Publications Clerk

Library and publications functions, performed by one publications clerk, include maintenance of records and files for publications authored by the Laboratory Research Staff, including publications co-authored with outside researchers, as well as for holdings of professional journals and other incoming media. Support includes searches for requested publications and materials for the Staff. Library holdings include approximately 1700 volumes in various scientific fields related to agriculture. Holdings of some professional journals extend back to 1959.

The U.S. Water Conservation Laboratory List of Publications, containing over 2000 entries, is maintained on PROCITE, an automated bibliographic program. The automated system provides for sorting and printing selected lists of Laboratory publications and is now accessible on LAN by the Research Staff. Publications lists and most of the publications listed therein are available on request.

MACHINE SHOP

C.L. Lewis, Machinist

The machine shop, staffed by a machinist and contracted assistant, provides facilities to fabricate, assemble, modify, and replace experimental equipment in support of U.S. Water Conservation Laboratory research projects. The following are examples of work orders completed in 1997:

- A stainless steel cold tray was designed and fabricated to facilitate leaf sample division for the FACE project. The tray was fabricated using a 12"x12"x1" stainless steel pan. A lid was made from 1/4" stainless steel flat stock machined to +.001" tolerance. A 1 ½"x6" copper tubing port was welded to the lid for filling the tray with liquid nitrogen. A 1/4"x4" stainless steel vent tube was welded to the lid at the opposite end from the input port. The lid was then welded to the stainless steel pan 3/8" below the pan lip.

- Two plexiglass boxes were designed and fabricated for radioactive waste storage from studies labeling DNA with radioactive isotopes. A double chambered 2'x4' box made from ½" plexiglass was machined to +.002" tolerance and assembled with a split hinged lid. A 5" sq. box was designed and fabricated for P32 freezer storage. This box was machined to +.002 tolerance and assembled with an inset lid with round handles.

- Seven stainless steel cylinders were designed and fabricated as grinding chambers for the SPEX Ball Mill to grind soil and plant material. The cylinders are 2.500" tall with an ID of 1.500". Lids are 1/4" stainless steel with a 1.930" OD and a .050" slot for O ring placement. The caps are .650"x2.210"OD with 2"-24 threads, and the OD is knurled for better gripping. All cylinder, lid and cap components are made from 316 stainless steel.

- A steel storage rack was designed and fabricated for OSHA approved gas cylinder storage. The rack was constructed from 1" steel tubing welded into 9 rectangular frames and the welded to 4"x12' steel plate on top and bottom. 1/4" holes were drilled 10.5" apart through the top of each rectangular frame. 1/4" eye bolts were inserted into each of these holes and 1/4" chain was attached to each eye bolt.

APPENDIX

APPENDIX A

Manuscripts Published or Accepted for Publication from October 1, 1996 through September 30, 1997

Adamsen, F. J., G. Wechsung, F. Wechsung, G. W. Wall, B. A. Kimball, P. J. Pinter Jr., R. L. LaMorte, and R. L. Garcia. Soil nitrogen dynamics in wheat grown under free air carbon dioxide enrichment (FACE). *J. of Environ. Quality*. (APPROVED) WCL# 1882. [1]

Badiani, M., A. R. Paolacci, F. Miglietta, B. A. Kimball, P. J. Pinter Jr., R. L. Garcia, D. J. Hunsaker, R. L. LaMorte, and G. W. Wall. 1996. Seasonal variations of antioxidants in wheat (Triticum aestivum L.) leaves grown under field conditions. *Plant Physiol.* 23:687-698. WCL# 1915.

Barnes, E. M. Remote Sensing applications to precision farming. International Symposium on Precision Agriculture. (ACCEPTED - OCT 1997) WCL# 2014.

Barnes, E. M., M. S. Moran, P. J. Pinter Jr., and T. R. Clarke. Multispectral remote sensing and site-specific agriculture: Examples of current technology and future possibilities. p. 845-854 *In* Proc. Int. Conf. on precision agriculture, Minneapolis, MN, 23-26 June 1996. WCL# 1937.

Barnes, E. M., P. J. Pinter Jr., B. A. Kimball, G. W. Wall, R. L. LaMorte, D. J. Hunsaker, F. J. Adamsen, S. W. Leavitt, T. Thompson, and J. Mathius. Modification of ceres-wheat to accept leaf area index as an input variable. ASAE Annual International Meeting. (ACCEPTED - SEP 1997) WCL# 2016.

Bautista, E., A. J. Clemmens, and T. S. Strelkoff. 1996. Characterization of canal operations under ideal anticipatory control. Unpaginated. *In* Proc. North American Water and Environment Congress, 22 June, 1996. WCL# 1930.

Bautista, E., A. J. Clemmens, and T. S. Strelkoff. 1997. Comparison of numerical procedures for gate stroking. *J. Irrig. and Drain. Eng.* 123(2):129-136. WCL# 1929.

Bouwer, H. Arizona's Long-Term Water Outlook: From NIMTO to AMTO. *Hydrological Science and Technology* WCL# 1976.

Bouwer, H. Artificial recharge of groundwater: Systems and guidelines. Water Management Conference Proceedings. (ACCEPTED - MAR 1997) WCL# 1957.

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Bouwer, H. 1996. From wastewater on the surface to water in the aquifer. p. 93-106 *In* United Nations development program proceedings of the biennial conference, San Diego, CA 11-12 Sept. 1995. WCL# 1890.

Bouwer, H. 1997. Predicting and managing inflitration for artificial recharge. p. 143-152 *In* 8th Biennial symposium on the artificial recharge of groundwater, Tempe, AZ, 2-4 June, 1997. WCL# 2000.

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[1] The WCL# corresponds to the item number on the USWCL Publications List. Please use the WCL# to request USWCL Publications.

Bouwer, H. 1997. Slug test interpretation for a situation in interbedded sand and clay. *Iowa Groundwater Quarterly* 8(3):7. WCL# 2012.

Bouwer, H. and T. Maddock. Effects of groundwater pumping on streamflow: Legal and hydrologic aspects. *Water Resour. Bull.* (APPROVED) WCL# 1924.

Bouwer, H. and T. Maddock. 1997. Making sense of the interactions between groundwater and streamflow: Lessons for water masters and adjudicators. *Rivers* 6(1):19-31. WCL# 2001.

Brahim, K., D. K. Stumpf, D. T. Ray, and D. A. Dierig. Effects of harvesting dates on oil yield and composition in Lesquerella Fendleri. *Ind. Crops and Products* . (ACCEPTED - DEC 1995) WCL# 1917.

Burt, C. M., A. J. Clemmens, T. S. Strelkoff, K. H. Solomon, R. D. Bliesner, K. A. Hardy, T. A. Howell, and D. E. Eisenhauer. 1997. Irrigation performance measures -- Efficiency and uniformity. *J. Irrig. and Drain. Eng.* 123(6):423-442. WCL# 1951.

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Clemmens, A. J. Level basin design based on cutoff criteria. *J. Irrig. and Drain. Systems* . (ACCEPTED - NOV 1996) WCL# 1810.

Clemmens, A. J., E. Bautista, R. S. Gooch, and R. J. Strand. 1997. Salt river project canal automation pilot project. p. 131-141 *In* International Workshop on Regulation of Irrigation Canals, Marrakech, Morocco, 22-24 April 1997. WCL# 1967.

Clemmens, A. J., E. Bautista, and R. J. Strand. 1997. Implementation of canal automation in Central Arizona. p. 302-307 *In* Proceedings of Theme A, Managing Water: Coping with Scarcity and Abundance, 27th Congress of International Association for Hydraulic Research, San Francisco, CA. 10-15 Aug. 1997. WCL# 1966.

Clemmens, A. J. and C. M. Burt. 1997. Accuracy of irrigation efficiency estimates. *J. Irrig. and Drain. Eng.* 123(6):443-453. WCL# 1887.

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Clemmens, A. J., T. F. Kacerek, B. Grawitz, and W. Schuurmans. Test cases for canal automation algorithms. *J. Irrig. and Drain. Eng.* (ACCEPTED - AUG 1997) (IN PRESS) WCL# 2004.

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Coffelt, T. A. and C. E. Simpson. 1997. Origin of the peanut. p. 2 *In* Kokalis-Burelle, N., Porter, D. M., Rodriguez-Kabana, R., Smith, D. H., and Subramanyam, P. (ed.) *Compendium of Peanut Diseases Second Edition.* APS Press, The American Phytopatholigical Soicety, St. Paul, MN. WCL# 1954.

Dierig, D. A. Lesquerella - New Crops Factsheet. *World Wide WEB New Crops Center* 1-4. Purdue University Bulletin. (ACCEPTED) WCL# 1956.

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